THE

ELECTRIC JOURNAL

VOL. XI

JANUARY - DECEMBER

1914

Publication Office

200 NINTH STREET

PITTSBURGH, PA

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Beginning the Second Decade

Ten years ago THE ELECTRIC JOURNAL was an innovation. It represented a unique idea. It established a new field in electrical journalism.

What was its origin, its purpose and what has it accomplished? As it is because the writer has had a part in its history that he has been asked to answer these questions, personal references may be permissable.

In 1902 I made two suggestions, which resulted in the formation of The Electric Club, (now The Westinghouse Club) among the young and older engineers of the Westinghouse Companies in Pittsburgh, and in the establishing of student branches of the American Institute of Electrical Engineers of which there are now about fifty, which have been followed by nearly as many more in other national societies. The idea in both was the fitting of young men for the growing needs of the electrical profession.

The club was both technical and social, older engineers gave talks and lectures and there were discussions on designing, testing and operating. The following summer the directors of the club met to plan for the coming year. When called upon I did a little thinking out loud, somewhat as follows:—"We are beginning a new year with many new men from various colleges; they should have substantially the same lectures that we had last year; the lecturers will not care to repeat the same material year after year; the material should be written or printed, it could then be handed to others who are unable to attend both here and at a distance; the papers might be printed regularly and be open to subscription; we should publish a paper; its contributors would be the engineering staff of a great company and the men who originate ideas and design machines, and who know the latest practice; they can write in a simple, direct way for the young men who are here to learn; and what they need to know is just what the student in the college and the engineer in the power house and the superintendent and manager also want to know." A committee was appointed and early in 1904 the first issue was published.

Its purpose was thus defined in the first issue:—"The JOURNAL is not a shot gun that is expected to hit everybody, but a rifle that is aimed straight at the young engineer. Our purpose is definite; to publish a journal for young engineers containing material suited to their needs and written in form to meet their education and experience." Intermediate between the formal transactions of the national societies and the ordinary engineering periodical which covers a wide field in a more or less popular and commercial style, the new journal presented live topics in a simple manner, not too advanced for the practical man, not too elementary for the technical engineer—both are interested in the same thing—and the aim was to get an intelligent treatment acceptable to both, avoiding alike the mathematically abstract and the commonplace descriptive. It put forth directly from the experts as their personal contributions, the information which in the older days constituted the mysteries and secrets of the inventor and the manufacturer. It was a new kind of medium of intercourse between the experienced engineer and the student engineer, between the man in the factory and the man in the field, between the maker and the user. Its scope was broad; the principles underlying design, methods of testing, commercial engineering, operating methods, steam turbines, air brakes and signals were supplemented by the human side of engineering and larger relations of the engineer to society.

The ten volumes now fill a two foot shelf with a sort of panoramic encyclopedia of electrical engineering. There are over 9 000 pages; there have been over 11 000 volumes bound; the average edition is now nearly 13 000 copies; and each year a complete topical index of the preceding years has made the back volumes easily accessible.

Since the JOURNAL was started the engine-driven alternator of 5 000 kilowatts has been superseeded by the turbo-alternator of six times the capacity; 50 000 volt transmission has been eclipsed by 150 000 volts; the carbon lamp has its counterpart in the nitrogen lamp, giving five times the light per watt; illuminating engineering has came into being; the output of central stations has been doubled twice. During the period also new interest has been taken in the training of young men and in the disseminating of engineering information. Instruction courses have been established by operating companies. The field developed by the JOURNAL is now shared by other publications, notably the monthly bulletins of various technical societies.

The JOURNAL has been directed by a publication committee of three. The first members were Mr. F. D. Newbury, editor, who had acquired usable experience as editor of the *Sibley Journal* at Cornell University, and gave to the new JOURNAL some of its best qualities; Mr. J. H. Smith, a vigorous, resource-

ful and indefatigible business manager, and the present writer, a sort of combination critic, contributor, and ways and means facilitator. After several years Mr. A. H. McIntire became editor and manager, which office he now holds, and further change made Mr. B. G. Lamme and Mr. P. M. Lincoln members of the committee; as assistant editors, Messrs C. R. Dooley, E. R. Spencer and C. R. Riker. But the men who have been named are only a few of those who have made the JOURNAL what it is. Several hundred voluntary contributors have shared in the interest and in the sentiment and purpose which have been the impelling motive in creating the JOURNAL. Many of the readers, by appreciative comment and fertile suggestions, have greatly aided those in authority.

As the JOURNAL enters its second decade after a long and progressive advance, it may well adhere to the general purpose and policy which have directed it in the past. There is every indication that the curves of electrical progress will continue upward and that the amount of work and the responsibilities which are placed upon the electrical engineer of the future will be far greater than even at the present time. During the past the JOURNAL has been read by thousands of young men who were entering their active engineering career, as well as by other thousands of older and more experienced men. There is no doubt but that it has been of substantial assistance to these readers. Its aim for the future is to be a still larger factor in making better engineers and broader men.

CHAS. F. SCOTT

The Change in Page Size

Since the JOURNAL was started ten years ago there has been a decided tendency towards standardization of trade and technical magazine sizes. Believing in standardization as we do, it has been thought advisable with the beginning of our second decade to make the change to the nine by twelve inch size which has already been adopted by some one hundred and thirty-five periodicals. While it is recognized that there are many advantages in the size heretofore used and the change has been made with considerable reluctance, it has been considered that the many advantages of the new arrangement, together with the fact that the publications of such societies as the American Society of Mechanical Engineers, and the Institution of Electrical Engineers are now changing over to the larger size, make this step decidedly desirable. Inasmuch as it is planned to begin a new topical index with the present year, that is, to run the index by decades, it is especially important that any such changes which may become desirable during the next ten years be made at this time.

Use the Topical Index

"Knowledge is of two kinds," said Dr. Samuel Johnson. "We know a subject ourselves, or we know where we can find information upon it." The owner of a set of bound volumes of the JOURNAL is in possession of a storehouse of this latter kind of knowledge in which few phases of electrical engineering will be found unrepresented. By means of the topical index, which is included as a supplement to this issue, he is able to locate readily the information scattered throughout the volumes on any particular subject. The advantage of the topical arrangement, in which all references to similar subjects are grouped together, instead of being scattered according to fortuitous differences in wording of their titles, is obvious. Equally obvious is the advantage of being able to find references to all the articles which have been published in the JOURNAL during ten years, in one location, instead of ten separate indexes.

The necessity for an index of this type is enhanced by the fact that a large proportion of the material indexed is of such living nature as to be practically as valuable today as when first published. The JOURNAL index thus becomes a working tool for frequent use in connection with every-day practice. A valuable feature is the listing of the tables, curves, diagrams, illustrations and words contained in each article, as a fair estimate of the size and importance of the article can at once be obtained from these items.

The topical index is merely a very condensed card index system in printed form. Hence it can again be made into a card system by pasting the items upon cards, and filing them under any existing index system.

The individual items covering similar subjects are not only grouped together under suitable headings and sub-headings, but wherever possible the individual items under a given sub-heading are grouped together according to subject matter, providing further ease in locating desired information. Where the items have no common subject matter they have in some cases been arranged alphabetically, according to the main idea.

In general, individual articles of a series are grouped together under the group headings, regardless of individual subjects of the separate articles. Where it was deemed advisable, cross-references have been filed under different headings, to provide a greater usefulness of the index.

In the present index, each question and answer in the JOURNAL Question Box has been given an individual subject heading, which, taken in conjunction with the topical heading under which it has been filed, provides ready access to all the information which has been published in this department.

Progress in 1913

A BUSINESS SURVEY OF THE YEAR

G. E. Tripp

THE year 1913 has been a period of absorbing interest to every man who thinks at all upon the great problems which confront the people of the United States. A new tariff law has been passed and opinions as to its effect upon business are so diverse that it is not possible to say where the weight of it lies. Not only do opinions differ by reason of the naturally different positions of different enterprises, but they do not agree even in exactly the same line of endeavor. For example, the writer's opinion that the electrical manufacturing business will not be adversely affected directly, to any serious extent, by the reduction in the protective tariff on articles of its manufacture seems not to be shared by certain other large electrical manufacturers, some of those having expressed the opinion in published interviews that either prices or wages must be reduced in consequence of the new tariff. It must be recognized that a diminution of business in any substantial industry will necessarily react on all other enterprises; and that, while the electrical manufacturing business may not be affected directly, it may easily feel these indirect influences.

The electrical manufacturers are not unique in holding different opinions as to the effect of the new tariff, for two of the leading representatives of the steel business hold diametrically opposite views. However, as in all cases where uncertainty prevails, the doubt is resolved on the side of safety and we see caution displayed on every hand until it has become one of the principal factors which has brought about, in the latter part of 1913, a distinct recession in business.

If a few months' test convinces business men that the results of tariff reduction are not serious, then the undue fears of those having them will be removed, those who have been in doubt will be reassured, and thereupon the incubus on business brought about through tariff doubts will be removed. The time required to make a test which will be reasonably reassuring or otherwise ought not to exceed six months.

With the reduction in the volume of business there must come an increase in idle cash. This will have a tendency to encourage investment buying of securities; and, if the tendency develops into a real movement, it will come at a fortunate time, for never have the railroads of the country and the public service corporations needed money more urgently for the purpose of refunding the millions of short-time obligations which will shortly fall due and for making needed extensions and improvements; and, when these enterprises are able to make these much needed improvements and extensions, which have been long delayed, there must follow a revival of general business.

To return for a moment to the question of a real movement toward the buying of investment sesecurities; we find many factors which tend to discourage such a movement, the principal one perhaps being the unfortunate position of the steam railroads—the largest business in the United States. It has been clearly shown in the recent hearings before the Interstate Commerce Commission in Washington that the net profits of the steam railroads have decreased while the gross earnings have been increasing. The railroads are now asking for a five percent increase in freight rates; but, even if this should be granted, it is quite possible that the relief will only be temporary because of the continued demands of labor for additional compensation. (It should be clearly understood that no comment is made upon the justice or right of labor to receive higher wages; this article only uses the fact and does not comment upon it.) The demand for higher wages inevitably results in arbitration, and arbitration means some concessions to labor. Not only are the railroads confronted with decreasing net earnings and constant demands for higher wages, but the natural growth of the country demands of them extensions and improvements which they cannot make without securing additional capital, and additional capital cannot be secured while the investor so clearly sees the dangers above referred to.

The only agency which can successfully deny the applications of a community for improvement in facilities, the demands of labor for higher wages and obtain capital at low rates is the government itself. It appears, therefore, that present conditions tend toward governmental ownership of steam railroads. In other countries this has usually meant stagnation of development and a decrease in efficiency and excellence of service. If private ownership is to continue, the inexorable progress of this ring of circumstances must of necessity be checked by fundamental economic law, for no statutory laws looking in that direction are probable. Should the country be entering upon a long period of depression with many thousands of men thrown out of employment, it would naturally bring about what is popularly known as the liquidation of the labor situation, that is to say natural conditions of supply and demand will be substituted for demands enforced by combination.

It should be recognized, however, that the combination of capital itself through which great corporations have been created, is one of the principal

forces operating against the so-called liquidation of labor. For example, in the time of small isolated manufacturing plants and railroads, difficulties with employees had nothing more than local significance, and a nation-wide strike in a particular industry was a matter infinitely more difficult to bring about. Therefore, we have the situation that combinations of capital support and strengthen combinations of labor; and, should the government in its campaign against so-called trusts, succeed in what appears impossible to achieve, that is to say, a more or less thorough disintegration of corporate combinations, there would probably follow more or less weakening of the labor combinations.

Closely allied to the operation of the above forces stands what the President conceives to be his greatest engine in the work of sustaining a system of competitive industries as opposed to large combinations, and that is the proposed currency bill, which is designed to enable small borrowers of money more readily to secure capital upon which to do business. Thus, without going further or mentioning such outside or extraneous matters as the threatening Mexican situation, we find that the year 1913 is bringing to an issue important problems which have a bearing not only upon our commercial and financial prosperity but upon the very fabric of our republican form of government. It is a good time for thoughtful men to think on these broad questions for they affect every man in every walk of life.

ELECTRICAL DEVELOPMENT IN NEW YORK CITY AND VICINITY

H. W. Flashman

The signing of the contracts between the City of New York and the two operating railroad companies, thus ensuring the early construction and operation of very considerable extensions to the present rapid transit facilities, constitute by far the most important event both to engineers and to the general public in New York City during 1913. The present subway, operated by the Interborough Rapid Transit Company, covers a single-track mileage of 72 miles and was originally designed to handle 400 000 passengers per day. The average load in 1913 was a million per day. The elevated lines, with a single-track mileage of 118 miles, are handling close to one million passengers per day. The Brooklyn Rapid Transit elevated lines, with a single-track mileage of 105 miles, handle 700 000 passengers per day. Under the recent agreements, additional third trackage is to be constructed on the Manhattan elevated lines so that, in future, through express trains can be operated on three avenues from the uptown districts direct into the downtown business section.

A total of $337 000 000 will be expended on the new Dual Subway System, of which the City of New York will supply $171 000 000 to be devoted to contruction work upon lines to be owned by the city. The Interborough Rapid Transit Company will contribute $105 000 000 and the New York Municipal Railways $61 000 000 towards construction and equipment. Under the completed Dual Subway System, it will be possible for a passenger to ride direct from Broadway by subway to any of the residential districts of Brooklyn, and there will be, in addition, two through subway routes on Manhattan in place of the present single route. Three additional tunnels are to be built under the East River. The mileage will total 618.7 single-track miles and, if used with full capacity, will carry more than three billion passengers per annum.

The physical connection of the New York, New Haven & Hartford Railroad and the Pennsylvania and Long Island Railroad systems by bridging the East River at Hell gate, thus giving through routes from New England to the West and to the docks at South Brooklyn, is a very important development. Together with this should be noted the remarkable industrial development which is going on in Queens Borough, through which this new railroad will pass.

To meet the power requirements of these increasing loads, the central stations are installing and contracting for turbines of larger capacity than ever before contemplated. Of the larger machines, contracts have been placed for three 30 000 kilowatt turbines and seven turbines of approximately 20 000 kilowatts capacity each.

The tendency among the companies supplying power is in the direction of concentration rather than toward the building of more power houses. With these large units, not only is advantage taken of the higher efficiency, but the power stations are enabled to more than double their capacity, without the acquisition of more real estate or the erection of further buildings, and with but slight increase in labor expense. These changes in the engine room have been carried on hand in hand with developments in the boiler room where the use of improved underfeed stokers has made it possible to operate boilers efficiently at much higher over-loads than formerly.

The year 1913 has been notable for the wide adoption of the Le Blanc rotary air pump as applied to surface condensers in connection with these large units. The high efficiency of this pump places at the service of the power station operator a better vacuum than has previously been obtainable under similar conditions with the expenditure of relatively less power for circulating water.

An interesting development among the New York surface railway systems has been the adoption of the stepless "Pay as you enter" center-entrance car. One hundred and seventy-five cars equipped with field control motors and automatic controllers are being built for service on the Broadway line of the New York Railways Company.

The continued success of hand operated unit switch control has resulted in such an increase as to make a total of 163 cars so equipped by the Public Service Railways of New Jersey.

There has also been considerable activity among the large central stations in extending their service to large power users, even to the taking up, in the case of the New York Edison Company, of the whole power requirements of one of New York's principal street railway systems. The importance of the electric heating load has also been brought strongly to the attention of the central stations as a means of compensating for the possible loss in income due to the development of low wattage incandescent lamps. In the towns surrounding New York, vigorous campaigns have been inaugurated which will mean a great deal to the development of the communities themselves. New York City is following the lead of other important cities in investigating the replacement of the present street-lighting system with equipment in line with the latest development.

There has been a standardization of certain interesting types of apparatus by the power companies as, for instance, the synchronous booster type of rotary converter for lighting work. Twenty-five cycle units of this type, in capacities of 3 000 kilowatts vertical and 3 500 kilowatts horizontal, are in successful operation. The use of the reduction gear has been extended still further, principally for driving direct-current generators and circulating pumps in conjunction with surface condensers. By this means an efficient high speed can be adopted for the turbine and the driven apparatus can be run at a speed best suited to its characteristics.

In the field of motor application, certain ideas have crystallized which promise far-reaching effects in business development Several manufacturers of apparatus which is customarily operated electrically have taken the stand that they will furnish a complete electrically-driven outfit and that their guarantee will cover the operation of the outfit as a unit and not as a pump, compressor or machine tool, etc. This plan has met withh general favor with the ultimate users as it places the whole responsibility on one organization, and it has had the effect of stimulating the business of the manufacturer.

This year has also been notable for the active interest shown by the financial houses in the electrical industry. Perhaps this interest has never been so great in the history of the electrical business as during the first three months of this year. Much valuable discussion has taken place and the profitable possibilities of electrical investment have been brought clearly to the attention of bankers. During the last nine months, however, owing to the high value of money, action on their part has been delayed; but the position which has been established should bear much fruit when market conditions return to normal.

The getting into motion of the "Society for Electrical Development," a society which contemplates membership from all those interested in the electrical industry with the slogan "Do it Electrically—Safety, Service, Efficiency, Economy," organized for the purpose of educating the public to the further uses of electrical energy, is by no means the least important of the achievements to be credited to 1913.

GOVERNMENT ENGINEERING WORK DURING 1913

H. M. Southgate

The passage of the first vessel through the locks of the Panama Canal brings that great engineering project, of all the electrical activities of the government, most prominently before the public. The Panama Canal may truly be said to be an electrical canal inasmuch as all operations are performed electrically, instead of by the more usual hand or hydraulic methods. Current generated at Gatun from the surplus water not required for lockage will be transmitted to all locks for power and lighting. Opening and closing the gates, filling and emptying the locks, and hauling the vessels in and out of the locks is performed electrically. Even the foot bridge to render safe passage over the top of the closed gates is placed in position electrically, and electric motors operate the various safety devices for protection of gates and locks.

To prevent a vessel in the locks from moving too far forward, heavy chain fenders are drawn taut into position across the lock at water level a few feet in front of the gates, and the emergency dams to prevent drawing off the lake in case a high level gate should be carried away by a vessel getting out of hand in entering the locks are built up electrically. The emergency dam consists of a truss of the cantilever type, built of structural steel, which can be swung out over the canal just in front of the head gate. When in position, guides are lowered to the lock sill and leaves forced between the guides, thus damming the flow.

As vessels will not be allowed to enter or leave the locks under their own power, hauling locomotives or tractors are installed. Four of these tractors will be used for each vessel, two forward and two astern, one on each lock wall. Owing to the different levels of the locks, and the necessity of locating machinery in the lock walls, these tractors must be able to mount steep grades with a rack and pinion track and pass around curves of short radius.

An elaborate central control system has been installed, so that all operations connected with valve and gate opening and closing and putting the chain fender into position are carried on from a central positon on each lock.

Coal handling plants installed at both ends of the canal and workshops and dry docks at the Pacific

end of the canal are other electrical developments.

The magnitude of the Panama Canal work has eclipsed similar work at home, such as the improvements of the St. Mary's river at the falls and the building of the new Sault Ste. Marie lock which is being carried out by the engineering corps of the Army. Only one new lock is required for this work, but its overall dimensions of 1 350 ft. by 80 ft. are comparable to those of Panama, and a somewhat similar arrangement of motor-operated valves and gates is being installed.

The year has seen the completion of the first government vessel electrically operated, the collier *Jupiter* having been recently commissioned and tested. This collier was built at the Mare Island Navy Yard and is equipped with a high-speed turbo-generator from which current is supplied to alternating-current motors directly connected to the propeller shafts. The success of this development will be watched with great interest and compared with the floating pinion gear drive installed on the government collier *Neptune*. These two colliers are practically sister vessels, and in each case the problem of obtaining low coal consumption and reduced weight is being solved by the use of higher speeds in the turbine and normal speed propellers, the connecting link in the *Jupiter* being by an electric reduction gear, and in the *Neptune* by a mechanical reduction gear. An adaptation of the reduction gear has been operated successfully on land for several years for driving direct-current generators by high-speed turbines, and this development is now being tried out for marine work.

The electric steering gear and electric bake ovens and ranges have passed through their probation period in marine work and have become part of the recognized equipment of the newer battleships and auxiliaries. The advantages of the electric steering gear, especially, should open up a broad field in the merchant marine.

The gyroscope compass has also come to stay and is being installed on all battleships. Although electricity is but a secondary factor in this device, it makes practicable the use of a master device located in the depths of the ship safe from gun fire. From the master compass the electric follow-up mechanism carries the indication of the true points of the compass to as many positions as may be desired throughout the ship.

The high powered government wireless station at Arlington, Va., has been in successful operation for several months, and arrangements are being made for the daily exchange of time signals with the Eiffel tower in Paris. This station is the first of a proposed chain of high powered stations intended to link the Canal Zone, Hawaii, Guam, Philippine Islands and Alaska. The site for the Canal Zone station of this system has just been definitely located.

Often in the past there has been a great deal of difficulty in supplying material to meet government specifications. Many times the service required special designs, but very often government engineers felt that apparatus superior to that generally offered commercially was desirable. With the improvement of standard electrical equipment this criticism has been partially met, while many of the unusual requirements of the government are now being recognized as unnecessary. The desire of the government engineers to modify their requirements to conform to commercial standards as far as the service conditions will admit and the steady improvement of commercial apparatus, is bringing the government specifications more nearly into line with the electrical manufacturers' standards.

THE AMERICAN ELECTRIC RAILWAY ASSOCIATION

Charles N. Black,
President

THE American Electric Railway Association, which now has a membership controlling over eighty percent of the electric railways of the country, has concluded a year of most successful accomplishments. To review the work of the organization in detail would but duplicate the published proceedings of the various Associations of which it is composed. However, certain accomplishments stand out so prominently that they may safely be said to indicate the line of action which the Association is pursuing.

In the preparation and publication of the Engineering Manual a very distinct contribution to the technical side of electrical railway operation has been made. The standards are set with great care and recommendations as to practice are made only after full deliberation and with great conservatism. It is this which gives value to these standards and recommended practices, and their collection in one volume so arranged as to afford ready access to all matters contained therein will undoubtedly prove of the very greatest use to the engineering staff of the various companies.

A committee of the Accountant's Association has been in conference with the officials of the Interstate Commerce Commission during the past year and, as a result, changes and amendments in the Standard Classification of Accounts have been prepared which will shortly be presented to all company members for their consideration. The work done by the committee extends over a period of several years, and the industry as a whole owes a debt of gratitude to this Association for its efforts in assisting in the preparation of a standard classification which reflects the ideas and methods of men actually engaged in the railway business, as well as those of government officials.

By the approval of the report of the Committee on Welfare of Employes, the Association has gone on record as advocating a policy to a marked degree

more liberal and advanced than any yet adopted by any organization of employers in America.

The movement to secure an equitable and satisfactory arrangement for the joint use of poles, as evidenced by the report of the committee having this matter in hand, has made marked progress, and when successfully carried out will be a noteworthy advance in the plan of beautifying the streets of cities and towns.

The past year has seen the inception of a plan for a careful, thorough and exhaustive study of the fare question by the inauguration of the Fare Research Bureau, which will unquestionably lead to big results. The Committee on the Cost of Passenger Transportation Service, after some years of careful consideration of this important question, which was referred to it, decided that only by such a study of the question as will fortify the companies with exact facts and exact figures relative to the cost of passenger transportation, can headway be made in the matter of securing a return commensurate with the services performed.

In the matter of Publicity, the *Aera,* the organization's magazine, has inaugurated a campaign which promises great results. Its aim has been to present to the members of the Association the true situation as regards present conditions and to educate them to the necessity of action along concerted lines. Through the skilled efforts of the *Aera's* editor, a carefully thought out and well directed plan of securing publicity to the proceedings of the various Associations at their convention was put into effect with a degree of success that shows beyond question that much can be accomplished by further development and expansion of this policy.

A resume of the work of the past year would not be complete without mentioning the magnificent exhibition arranged for at the Atlantic City Convention by the Manufacturers' Association. It was a display of electrical railway apparatus and devices which reflected in a graphic manner the development and improvement in electric railway practice, and illustrated how engineers and supply men have marched together in the wonderful advance made in electric railway progress.

The work of the Association during the year has shown conclusively that the Association is fulfilling the purpose for which it was organized; that it has a well defined field of action; and that the task before it is one worthy of the best thought and efforts of the high class of men who are giving so freely of their time and energy to the organization's welfare. The present is an important period in the life of the Association, and the most important work that lies before it during the coming year is, in my opinion, the question of public relations. It is the purpose of the present officers to deal with this important matter in a way which the magnitude of the subject demands, through a Committee on Public Relations, recruited not only from the abl[illegible] in the ranks of the railway operators, but a [illegible] the banking and manufacturing interests as well. Practically all of the work of the American Association is closely related to this Committee, and its importance cannot be over-estimated.

The problem with which this Committee must deal may be stated briefly in this way:—

Conditions in the electric railway industry are unsatisfactory; it is being subjected to attack from many directions and from many sources. Capital has been driven from the field of electric railway investment; new construction has halted; theories antagonistic to the interests of the holders of electric railway securities are being advanced on every side; the existence of the industry as at present constituted is threatened; capital invested in good faith is in danger of practical confiscation.

This state of affairs has arisen, it is believed, because of a lack of understanding on the part of the public of the real conditions existing, and because there has never been a concerted organized attempt made to correct this misunderstanding. To secure a correction of these conditions, to present the true facts to the public and to formulate a definite working policy which may be pursued by this Association in its future action along the lines indicated, is the scope of the Committee on Public Relations.

If such a policy as will take care of the matters to be considered by this Committee can be formulated during the coming year, a very distinct forward step will have been taken, and if, in addition, the work already begun through *Aera* and through such small beginnings in a publicity way as have been attempted, can be further pursued, a period will be inaugurated which will be a banner one in the history of the American Electric Railway Association.

THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

F. L. Hutchinson
Secretary

A REVIEW of the activities of the American Institute of Electrical Engineers for the year 1913 indicates the numerous and varied advantages of membership to the individual electrical engineer and the constantly increasing usefulness of the organization to the entire electrical engineering profession.

The Section and Branch organizations have continued to show remarkable activity, and their value to the local membership, as well as their influence in the work of the Institute, is becoming more apparent each year. Several new Branches have been authorized in technical institutions during the year, and Sections have been organized in Spokane and Panama. There

are now thirty Sections located in the principal cities of the United States, Canada and Mexico and forty-seven Branches in institutions of learning having courses of instruction in electrical engineering. Statistics for the year show that the number of meetings held by the Sections, and the average attendance at these meetings, have been greater than in any previous year.

In addition to the local meetings referred to above, and regular monthly meetings at New York, the following conventions and other Institute meetings have been held during the year:—

A Midwinter Convention held at Institute headquarters in New York, February 26-28, 1913, under the auspices of the Standards Committee, marked a departure from the usual program of Institute meetings of the convention type, being the first convention to be held in New York since the Institute was organized. The meeting was eminently successful from the standpoint of the results accomplished. The data presented in the various papers and discussions will be of great value to the Standards Committee in formulating its revision of the Standardization Rules. Forty-four papers were presented in brief abstracts, and the balance of the time was devoted to the discussion. The registered attendance at the convention was 422.

A two-day meeting was held in Pittsburgh, Pa., on April 18 and 19, under the auspices of the Pittsburgh Section, and the Committee on the Use of Electricity in Mines. Eight technical papers were presented, and the total registered attendance was about 300 members.

The annual convention was held in Cooperstown, N. Y., June 23-27, and it will go down in the annals of the Institute as one of the most profitable and enjoyable ever held. Twenty-six papers were presented, the number being limited in order to eliminate parallel sessions and afford longer time for discussion.

The Fifth Annual Pacific Coast Convention was held in Vancouver, B. C., on September 9-11. Six excellent papers were presented on a variety of subjects, some being especially applicable to developments and industries on the coast. The registered attendance was 154, and the convention was decidedly successful, from a technical as well as from a social standpoint.

On October 13, the Institute held a meeting in Philadelphia, Pa., under the auspices of the Philadelphia Section. Three technical papers were presented at this meeting, and the registered attendance was 204.

The Institute's policy of holding general meetings in various sections of the country has proved to be one of the most valuable measures introduced into its activities in recent years. Not only do these meetings afford opportunities for the presentation and discussion of technical subjects of interest to a large proportion of the membership, but they also provide suitable social occasions for renewing and extending acquaintanceship with other engineers. Furthermore, the meetings emphasize the national character of the Institute and widen its scope and influence.

Upon the suggestion of President Mershon, the Electrophysics Committee arranged with Professor Edwin Plimton Adams, of Princeton University, for the presentation before the Institute of a series of lectures on the subject of radio-activity. Professor Adams, one of the best known authorities on radio-activity in this country, delivered the lectures in New York during the latter part of March and the early part of April. The widespread interest manifested in these lectures prompted the Board of Directors to authorize the publication of the series in the Institute Proceedings in order that the entire membership might have an opportunity of obtaining practical and theoretical knowledge of this interesting and important subject. These lectures have also been reprinted in pamphlet form for sale at a nominal price.

An index to the Institute's Transactions, in two volumes, covering the period from the organization of the Institute (1884) to 1910 inclusive, was completed during the year under the direction of a committee appointed for this work; a similar index is now published in each annual volume of the Transactions, beginning with 1911. The index consists of two separate parts; first, an index of papers in which they are classified in natural groups and chronologically arranged in each group; second, a topical index of specific data and information, arranged alphabetically This index is of great value to searchers for data upon any given subject, as there is a mass of valuable information in the Transactions, much of which cannot readily be found except by reference to the classified or topical index.

During the early part of the year, the Institute took up the important subject of electrolysis, and initiated a movement for the formation of a national committee to consider the subject broadly and endeavor to agree upon basic principles or methods of procedure to be followed in case of electrolytic disputes. Several other technical organizations were invited to appoint representatives upon the proposed joint committee, and nearly all accepted. The committee is now organized, and it is expected that the results of its labors will be valuable, not only to the engineering profession, but also to the general public.

The Institute has undertaken to participate in the work of the International Illumination Commission, a body organized and to be conducted somewhat similarly to the International Electrotechnical Commission, and has recently appointed representatives upon the Commission's U. S. Committee, upon which two other American organizations are also represented.

In the Institute's library a very important work is now carried on in the research department, which was established about three years ago in order to place the facilities of the library at the service of out-of-town members. Upon application, bibliographies are prepared on any desired engineering subject, and, if desired, copies, abstracts, translations, or photographs are supplied. A small fee is charged for this work. Since the inauguration of this service over 500 bibliographies have been prepared for members and others in various parts of the world.

By the unanimous vote of all the members of the Edison Medal Committee, the fourth Edison Medal was awarded on December 13, 1912, to Mr. William Stanley, of Great Barrington, Mass., "for meritorious achievement in invention and development of alternating-current systems and apparatus." The presentation was made at the Annual Convention at Cooperstown, N. Y., in June, 1913.

Considerable work has been done in connection with the International Electrical Congress to be held in San Francisco in September, 1915. The Executive Committee of the Committee on Organization has been reorganized, and a list of twelve Sections, into which the congress is to be divided, has practically been decided upon, as follows:—Generation, transmission and distribution; apparatus design; electric traction and transportation; electric power for industrial and domestic use; lighting and illumination; protective devices; electro-chemistry and electro-metallurgy; telegraphy and telephony; electrical instruments; central station economies; electro-physics; miscellaneous. The Executive Committee of the Committee on Organization is now actively at work upon its preparations for the congress.

The Institute has also appointed its representatives upon the Committee of Management of the International Engineering Congress, which is to be held during the week following the Electrical Congress. This committee is also active in its preliminary work of organization.

With the sanction of the Board of Directors, an innovation in the method of carrying on the work of the Institute was introduced and put into operation by President C. O. Mailloux upon his accession to office last August. The plan provided for the grouping of the various committees of the Institute into six departments, with a vice-president and a manager assigned to each department as councillor and vice-councillor respectively; these twelve officers, with the addition of some ex-officio members, forming a Ways and Means Committee, principally for the purpose of correlating the work of the various committees. Important changes have also been made in the organization of some of the committees. Chief among these was the formation of an Electric Power Committee, comprising seven sub-committees upon the following subject:—Power station, power generation, protective apparatus, transmission, distribution, economics, and engineering data. Additional technical committees have been authorized and appointed during the year upon the following subjects:—Use of electricity in mines; use of electricity in marine work; records and appraisals of properties; electrically-propelled vehicles; technical lectures.

The numerous committees and officers of the Institute are active in the special work and duties within their scope; the policy of coöperation with other technical societies is being extended through many joint committees and otherwise; the field of the Institute's activities is broadening; and there is every indication that the future results will be of steadily increasing value to the engineering profession.

THE STEAM POWER PLANT SITUATION

H. A. Rapelye

In a review similar to this, written at the close of 1912, the general tendency toward large turbine units was indicated. This has been well born out in the past twelve months, as during this period several machines of 30 000 kw capacity have been purchased. In one instance three of them were included in a single order, marking what is probably the most significant prime mover contract ever awarded.

In addition to their remarkably high cyclic efficiency, about 75 percent, these units possess mechanical features of the greatest interest. Each unit is in two complete sections, high and low pressure, each section driving its own generator. This construction, while a partial reversion to the practice of 1900 or thereabouts, when two sections were coupled to the same generator, has been adopted for several reasons. The most important of these concern the reliability and efficiency of the units. As they will be used practically continuously at or very near their rated capacity, both qualities must be present in the highest degree, even at some additional initial cost.

With the completion of the design for these units the point in prime mover art has been reached at which the user of electrical generating apparatus has all limits of unit size removed so far as the apparatus itself is concerned. It is possible to state at this time that a turbine unit of 100 000 kw capacity can be successfully designed and constructed whenever there is a power system which can make use of it to advantage.

Low pressure, non-condensing and bleeder turbines, as well as the large class generally referred to as small turbines, find a better market with each successive year. This probably will not be true of the low pressure turbine five years from now. On the other hand, it will then be even more applicable in the case of the bleeder machine. The latter is, in a broad sense, the universal turbine, since it combines in a single unit, all of the other types. By comparatively simple attachments it may be arranged to operate as either a complete expansion, non-condensing, low

pressure, or mixed pressure machine. Several applications of such machines, capable of automatic operation have been made in the past year.

Reduction gearing for turbines has completely justified the claims of those responsible for its original development. One of the most interesting problems of modern mechanics was presented in the design of such gearing. The long, slender pinion shaft, made necessary by the high rotative speed of turbines, is subjected to considerable twisting, and to insure proper action of the gear teeth under these conditions some exceedingly clever engineering was required. The American solution consisted in the introduction of an hydraulic support for the bearings of the pinion shaft, which is thus enabled to align itself automatically in such a way as to apply an equal load to all portions of the tooth surfaces. Europe has been slow to adopt or commend this arrangement until within the last few months, when the most eminent of foreign turbine and gear builders accepted it as the correct solution. He has used it in another form, almost equivalent, since that time. The fifty or more American built outfits involving comparatively high speed turbines connected through this gearing to low speed rotative apparatus of various kinds continue to give complete satisfaction.

The great impetus given to the condenser building art by the standardization of the turbine is still in evidence. During the past year there have been recorded a number of instances of surface condensers which were giving heat transfers approximately twice as great as those which were considered to be the limits of older practice. Although these results are due to an increased appreciation by designers of the importance of several factors, the greater part of the credit must be given to the hydraulic air pump. Although a decided innovation at the time of its introduction about five years ago, it now has the endorsement of almost every important condenser builder in America and Europe, and in the most approved form its positive action and general desirability mark it as one of the most effective elements in the success of modern power plants. Its influence is not confined to surface condenser work, for the jet condenser has also made great forward steps since the first application of this principle to air removal. Many plants located in warm and humid climates, where the effectiveness of cooling towers or spray nozzles was reduced to a low point, have found wonderful possibilities in jet condensers equipped with these air pumps. Due to the close approach to theoretically perfect performance which they insure, vacua have been greatly increased, or condensing apparatus with a water cooling system has been installed where it was previously considered unjustifiable.

The field of the internal combustion engine is not undergoing, and probably will not undergo, any further changes of great importance. It is probable that the coke oven gas engine will find a wider usefulness as the iron and steel manufacturers adopt more widely the use of biproduct coke ovens. Gas producers are so intimately associated with internal combustion engines that the same remarks apply to them. Along the lines of last year's suggestion, it is interesting to note that producer gas has been satisfactorily demonstrated to surpass either oil, coke or electricity in brass melting, whether the fuel used be anthracite or bituminous. There appear to be considerable possibilities along these lines.

Mechanical stokers of the forced draft type may be compared to the large capacity turbine in that they have now reached a point where the limits of capacity lie with the boiler and flues rather than with the stoker. It is possible to burn on such a stoker, with good efficiency and low operating cost, sufficient coal to generate more heat than the present type of boiler can absorb. From such combustion there results a volume of burned gas so great that new practice in flue and offtake design must soon develop.

TENDENCIES IN AIR BRAKE DEVELOPMENT

S. W. Dudley

FOLLOWING naturally after the development of new air brake devices and methods to meet the new operating requirements of the past few years, the year 1913 has been characterized by further improvement of details rather than the introduction of advanced types of complete apparatus. There has been a marked advance in the degree to which the air brake has come to be recognized as a source of revenue as well as of convenience and safety in operation. An example is the extension of the principle of the automatic car and air coupler to the automatic connecting of whatever wires have to extend continuously between the cars, such as control circuits, signal circuits and brake circuits. The principle is not a new one, but until the past year what had been accomplished in the direction of adaptability, reliability and low cost of maintenance left much to be desired. Special study of the severe service conditions of the New York Interborough Railway was made, with a view of producing a coupler automatically connecting the draw-bars, the air brake hose connections and the electric train circuits in such a way as to satisfactorily meet the requirements of congested service where the importance of time justifies every ffort in the direction of automatic and time saving apparatus. Twenty cars of the Pacific Electric Company are being equipped with this type of coupler.

The design and construction of brake valves, for use with light city service car brake equipments, and those for heavier multiple-unit cars running either singly or in trains, have been improved by

providing a greater range of adaptability, more convenient manipulations and simpler construction.

An interesting development in air compressors for electric road service during the past year has been brought about by the use of a phase converter for driving the compressor. This idea is in reality an outgrowth from the dynamotor-compressor principle, which involves the intermittent operation of a compressor driven from a continuously operating dynamotor through an automatic air-operated clutch. The recent electrification of a portion of the Norfolk & Western Railway, using single-phase transmission and polyphase induction motors on the locomotives, necessitates the use of a continuously running phase converter on each locomotive. It was seen that this converter could be used to advantage for driving the compressor. A three-cylinder compound compressor of the type now in use on the Pennsylvania Tunnel & Terminal locomotives was modified so that a gear and pinion connection could be made to the extended converter shaft. Machines of this type are now being installed on the N. & W. electric locomotives. The normal speed of the converter shaft is 750 r.p.m. and that of the compressor crank shaft is 220 r.p.m.

Further improvements in motor-driven air compressor design and construction have been in the direction of providing more effective protection to the working parts of the compressor from dirt, insuring sufficient lubrication and the elimination of "oil throwing." If dirt can be kept out of the compressor and if the lubricating oil can be retained in the compressor and made to perform its intended function instead of being passed on by the compressed air into the storage reservoirs and thence into the brake system, the problems of maintenance will have been largely solved. Progress in these directions has been made by means of improved design and construction of pistons and cylinders, the use of adequate protectors for the compressor intake, and the complete closing of the compressor crank case, except for one outlet connected to the intake passageways which affords the necessary outlet to take care of air pulsations.

The tendency in the direction of a composite or universal equipment having a simple form of triple valve as a base to which any portions can be added as required according to the character of the service demanded of the installation, as noted a year ago, has continued, the "universal" type of valve device being recognized as a logical development following the independent solution of individual problems as they have arisen in the past. This form of apparatus has proven extremely adaptable on account of the slight changes in its unit portions required to meet a wide range of conditions. A case in point is the application of this general form of apparatus to the one man operated cars of the Illinois Traction System, in which case modifications of the apparatus had to be made to enable the motorman, by means of the brake valve handle, to manipulate not only the air brakes but also control the operation of sanding valves and door opening mechanisms. During the past year the cars of the Pacific Electric Company, the Peninsular Railway Company, the San Jose Railway Company, the Portland, Eugene & Eastern Railway, and experimental trains on the Metropolitan Elevated of Chicago, have also been equipped with air brake apparatus of the universal type, arranged for pneumatic operation at present, but with the possibility of changing to electro-pneumatic control of the brakes at any time, by the addition of the unit portion carrying the service application, emergency application and release magnets and the automatic emergency application switch. In some of these installations the brake valve used is of the combined straight air and automatic type so that by the movement of the single brake valve handle the motorman can operate the brakes on a car running singly as with the simple type of "straight air" equipments while for train operation the features required for the operation of the automatic brake apparatus are provided, these features being so combined that either pneumatic or electro-pneumatic control may be employed as desired.

During the year the Pennsylvania Railroad Company has tested, adopted as standard and equipped some 450 of their standard "P-70" steel cars running in through passenger service with the universal control (UC) brake equipment. This apparatus is similar to that already referred to in connection with electric road service but adapted to the requirements of steam railroad passenger service. The primary distinction between steam and electric service from the standpoint of brake operation, lies in the methods by which the compressed air required for braking purposes is made available. In steam road service, the source of air supply is located on a single vehicle (the locomotive) at the head end of the train, and a single pipe (the brake pipe) extends the entire length of the train. This serves the double purpose of conducting to each car in the train the supply of compressed air required for the operation of its particular brakes, and providing means for causing the automatic brake apparatus on each car to respond according to the manipulation of the engineer's brake valve handle. In electric road service, however, there is a source of air supply in each motor car and by the use of a second pipe through the train, called the main reservoir pipe, connecting the main air reservoirs of each motor car to each other and to the operating brake valve, the supply from each motor car is made available for braking purposes on the entire train.

The use of the universal type of air brake

equipment affords not only a greater protection against the more or less serious difficulties experienced in handling long trains with the older type of brake, but also provides a brake having greatly improved pneumatic service and emergency features and paves the way for the adoption of electrical control for brakes in both electric and steam road service as soon as complete trains of this equipment become the rule.

In order to determine what might be expected from the various available combinations provided by this improved equipment the Pennsylvania Railroad Company made a thorough investigation of the performance of the new brake as well as of the brake equipment now in common use. These tests were made on the Atlantic City division of the West Jersey & Seashore Railway, near Absecon, N. J., February to May, 1913, using a fully equipped train consisting of a class K-2-S locomotive weighing 200 tons and twelve P-70 steel passenger cars weighing 122 000 lbs. These tests are the most scientific and comprehensive investigations of the different factors affecting the operation of brakes on steam road passenger trains undertaken since the Westinghouse-Galton trials of 1878 to 1879.

The results of the Lake Shore emergency brake tests of 1909 which appeared in the Master Car Builders' Association Proceedings for 1910, directed special attention to the important influence of the foundation brake rigging and brake shoe performance as affecting the stopping of modern heavy rolling stock. These tests showed clearly the necessity for realizing, as nearly instantaneously as possible, a retarding force as high as the limitations of track and equipment would permit if emergency stops, especially at high speeds, were to be made in as short a distance as desirable.

The four factors which have a controlling influence on the length of stop are, the maximum brake cylinder force, the time in which this is obtained, the efficiency of the brake rigging in multiplying and transmitting this force to the brake shoes and the mean coefficient of brake shoe friction. All but the last factor can be controlled or properly provided for in advance by correct design and installation. On the other hand, the experience of recent years has repeatedly demonstrated that no one of these four factors can be neglected without a corresponding loss in effective retarding force. It is therefore of the greatest importance to distinguish and give due consideration to the controllable factors mentioned, in order to compensate for the unavoidable variations in brake shoe friction. That these variations have more than a merely nominal effect, follows from the fact that the brake shoe, considered as an element of the mechanical system transforming the force of compressed air into the retarding force at the rim of the wheels, is low in efficiency, averaging in the neighborhood of ten percent, for stops from a speed of 60 miles per hour. Consequently a variation in brake shoe performance can cause a considerable percentage of change in the mean coefficient of brake shoe friction and a corresponding change in length of stop, the latter being subject to a range of variation of as much as 20 percent or more, due to brake shoe condition alone.

Briefly, the Pennsylvania Railroad tests showed that in order to make the shortest possible emergency stops the following factors must receive special attention:—

1—*The time from the starting of brake application until the maximum available braking force is attained*—By whatever amount this time is lengthened the length of stop is correspondingly affected. As this factor has its effect at the beginning of the process of braking, when the speed if the train is highest, its influence on the length of stop is most direct and important. Modern brake equipments operating with electro-pneumatic control require but two seconds from the time the application is commenced until maximum force is realized on every car.

2—*The amount of maximum braking force realized*—The amount of braking force which can be used in any given installation depends upon the character of the service, the type and construction of the foundation brake rigging, trucks, etc., and the characteristics of the air brake apparatus employed. When freedom in all of these directions is afforded the brake apparatus can be applied to give a maximum emergency braking force as high as is practicable, considering the necessary margin of safety against wheel sliding under adverse operating conditions. At present the total emergency braking pressure delivered to the brake shoes of modern passenger cars in both steam road and heavy traction service ranges from 125 to 180 percent of the light weight of the car.

3—*The efficiency of the brake rigging*—With a poorly designed brake rigging, a material loss is experienced in multiplying and transmitting the force of compressed air developed in the brake cylinder to the brake shoes where useful work is performed. The direct losses resulting from improper angles, deflection of members, friction of parts, interference due to lack of sufficient clearance, and maintenance troubles are not the only, and probably not the most important losses experienced. The location of the brake shoe with respect to the horizontal center line of the wheel has a direct bearing upon the performance of the air brake equipment and upon the distribution of weight on the different axles of the truck, as well as upon the resultant effective normal brake shoe pressure. This is because a pull on the brake shoe more than equal to the weight carried by the wheel sets up force rela-

tions which are sufficient to cause a low hung brake shoe to travel downward along the circumference of the wheel. The horizontal component of this movement causes a material increase in travel of brake cylinder piston above that contemplated in the design of the air brake apparatus with the net result that a lower brake cylinder pressure is obtained and correspondingly less effective braking forces realized. The vertical component of the shoe's motion is at the expense of compression in the truck equalizer or bolster springs and not only affects the riding qualities of the car, but on account of the new alignment of forces set up between the brake shoe, the journal bearing, the pedestal and the rail, causes a redistribution of the weights carried by the different wheels under the car. This tends to cause the sliding of such wheels as become partially supported by the low hung brake shoes, accompanied by a lessening of that wheel's pressure upon the rail at the expense of an increased weight imposed upon the other wheels. With modern heavy cars and under the heavy brake pressures required for their adequate control, it has been demonstrated that the desirable relation of force and reaction between brake shoes, truck members and wheels, cannot be secured when using a brake shoe on only one side of the wheel. By using two shoes, one on each side of the wheel, it is possible to obtain a satisfactory design with respect to all of the elements referred to, and this type of brake rigging, known as the "clasp brake," has come to be generally recognized as the only satisfactory solution, if the highest efficiency is to be obtained. Development in this direction has been slow in this country, but with the more severe conditions now to be met and with the superiority, efficiency and adaptability of this type of rigging thoroughly established in the Pennsylvania Railroad tests referred to, as well as by the thoroughly satisfactory performance of this type of rigging on heavy rolling stock in every day service on other railroads, notably the New York Central Lines and the New York, Westchester & Boston, it is to be hoped that the subject of truck brake rigging will soon be given the attention in this country which it seems to have received abroad almost from the start, clasp brake rigging having been the common practice in England and on the continent for many years.

4—*The condition of the brake shoe, both as regards quality and fitting to the tread of the wheel*—So far as stopping power is concerned the brake shoe deserves first consideration, certainly more than it has usually received. Shoes of proper material, a right relation of the forces and reactions on the brake shoes, care in renewals and adjustment are matters of prime importance. With the most efficient type of air brake mechanism and the best brake rigging possible, it is not at all difficult to bring about brake shoe conditions (such, for example, as the difference between a well worn, well fitted shoe and shoes newly applied; warped shoes not having a good bearing, or shoes which have been overheated and badly burned) which can change the length of the stop 20 to 30 percent. It is, therefore, quite clear that notable improvement in any one or all of the foregoing fundamental elements affecting the stopping of trains can be entirely neutralized by neglecting to take into account the possible results of poor brake shoe performance.

It has seemed fitting to dwell somewhat at length upon these fundamental considerations in the performance of brakes on modern rolling stock, not so much because of the novelty of the conclusions as on account of the evident lack of appreciation of their importance on the part of those not especially conversant with the technical problems involved in brake design and performance. The facts mentioned have been known and discussed ever since the classic Westinghouse-Galton brake trials, the details of which can be found in three papers by Capt. Douglas Galton before the British Institution of Mechanical Engineers in 1878 and 1879. Every important investigation since that time has but served to give added weight to, and bring about a more complete understanding and application of the principles enunciated in that historic report.

During the last few years the air brake has advanced to a point where its full capacity cannot be realized, where in fact diminishing returns will attend further progress in this direction, unless the other elements associated with it in the production of retarding force are brought to a similar degree of efficiency. This is coming to be more and more generally appreciated and the present interest in this aspect of the air brake problem, on the part of electric traction as well as steam railroads, promises notable progress in the future.

PROGRESS IN RAILWAY SIGNALING

HAROLD MCCREADY

THOSE interested in the manufacture of apparatus for railway signaling found last year a busy one. While no extraordinarily large installations were made and no startling developments occurred in an engineering way, still there was a consistent market for all kinds of signal material. In fact, looking at the matter from the standpoint of the volume of business done, last year tops all others excepting perhaps 1910. A large proportion of the business resulted from the extension of alternating-current block signal systems on both the large trunk lines, steam and electric, and on the interurban roads. For the trunk lines the Pennsylvaia, the St. Paul, and the Southern Pacific, have been the most prominent in the adoption of the alternating-current system, and

continually increasing stretches of their main lines are being so protected.

The interurban field, too, has broadened considerably. In Indiana alone, about two hundred and fifty miles of single track have been signaled; the well known Chicago, Lake Shore & South Bend (6 600 volt, 25 cycle propulsion), running from Chicago through Gary, offers a fine example of modern signaling for a high-speed road. By an ingenious circuit scheme, known familiarly as the T.D.B. (Traffic Direction Block) system, single track interurban roads are enabled to allow two properly spaced cars to proceed through the block in the same direction, opposing cars being held at a siding at the other end of the block; traffic is thus greatly expedited in rush times, and safety is guaranteed as both cars are protected against both head and rear end collisions. The traffic direction block scheme is therefore generally conceded to be a great improvement over previous schemes which allowed an indefinite number of cars to enter the block in a given direction without any regard to spacing, thus leaving an opening for rear end collisions. Such a system is of course not required on double track roads, like the Pacific Electric, or the Oakland, Antioch & Eastern, two of the most important roads in California, which have been extensively signaled during the past year, light signals being exclusively used. Practically all new work is being done on the basis of the continuous track circuit; trolley contacts and other such attachments have been found inadequate for high-speed service.

Lights signals consisting of a properly designed lens or combination of lens and reflector illuminated by an incandescent lamp, properly hooded and built into a dark sheet iron background are now quite extensively used on trolley roads for both day and night service. Such signals, particularly if set up against a background of foliage afford a splendid indication; in those cases where light signals are set up against the sky, the sheet iron background serves to isolate or bring out the illuminated lens from the sky. On account of their simplicity and ease of maintainance, not to mention the low first cost, light signals make a strong appeal to the practical man and a great deal of research is being done in the way of designing and developing special lenses, mirrors, and concentrated filament lamps to secure a strong beam of light, distinct, even in the brightest sunlight at a great distance, and through a considerable angle. By means of opaque interference rings and like devices, light coming from the outside (for example from an arc headlight or even from the sun in the later hours of the day) is prevented from re-issuing from a "dead" signal by interior reflection and thus giving rise to so called "phantom" indications which, if pronounced enough, might be dangerous. On the electrified sections of the steam roads where the catenary makes it difficult to secure a good indication for a semaphore, light signals should make an especially good showing and important developments in this direction may be expected in the near future. It looks as though the science of optics is to be added to the requirements of the signalman, already quite an electrical and mechanical engineer.

The automatic stop, a device applied to an engine or a car to prevent collisions resulting from passing, either unknowingly or maliciously, a danger signal, has received much attention and two or three very promising devices are now being tried out. The best of these include speed control features which serve to cause a train to slow down at a "caution" signal so that the "home" signal will not be overrun if at danger. The general feeling seems to be that the automatic stop should be effective only in case the engineer fails to act; it serves simply as a check on him and is ordinarily inert. At present, however, the time is not ripe for the stop. Development work is still going on. Before the railroads adopt such a device its worth will have to be proven conclusively.

The insulated rail joint, as everyone knows, is one of the most important features of the track circuit; it is important to maintain a high insulation between adjacent track circuits, and for this reason, the integrity of the insulation joint must be assured. In the past, fibre has been employed to insulate the fish plates or filler blocks from the rail, but fibre, being made up on a paper or rag base, rapidly deteriorates due to the absorption of moisture and the rough service For this reason, it is pleasing to note that considerable progress has been made in the development of a bakelized canvas substitute for fibre. Although a great deal yet remains to be done, the outlook seems promising, because bakelized canvas can be made almost absolutely waterproof and is many times tougher and yet more flexible than fibre.

The latest new railroad terminal is the one being constructed at Kansas City, and the interlocking system is to be of the electro-pneumatic type, which has given such successful service in the Pennsylvania's terminal in New York and at Broad Street, Philadelphia as well as at the great terminals in St. Louis and Boston. A new development in the purely electric interlocking system is the use of two central feeding mains which serve to supply power to the various switches and signals through controlling relays located at the various functions to be operated, the controlling relays themselves being operated from an interlocking tower over comparatively small wires generally arranged in cables. This system is much more economical in copper than the older systems where individual feeding wires, carrying the full current for operating the motor, are required between each switch movement and the tower. In connection with this system an alternating-current indication scheme is also frequently used, the idea being that crosses between

the alternating-current indication mains and the direct-current operating mains will not result in a false indication, since the indicating apparatus responds only to alternating current.

It is interesting to note that American signal material is now being used abroad. During the past year a considerable quantity of signaling apparatus was supplied to an English contractor for installation on a German road. At the present time the electrification of the Victorian Railways in the vicinity of Melbourne, Australia is attracting a great deal of attention, and there is a very strong probability that the larger part of the signal apparatus will be manufactured in America. The coming year will also witness the the electrification of the Philadelphia to Paoli suburban service on the main line of the Pennsylvania Railroad. It is probable that alternating-current propulsion will be used, and undoubtedly a considerable amount of apparatus will have to be designed to meet the signaling requirements.

THE GENERAL APPLICATION OF ELECTRIC POWER

H. D. JAMES

THE more recent developments in the use of electric power consist largely in the application of electricity to new problems, in the improvement in efficiency of installations already made, and in adjusting conditions to make the rate of output of power stations more uniform. Progress has been made in the conservation of energy by the increased application of electric braking. This is especially noticeable in the application of motors to steel mill rolls, cranes, mine hoists, etc. By causing the motor to be operated as a generator, the mechanical energy stored in the load can be converted into electrical energy and, where conditions are suitable, this energy can be returned to the line. In other cases, the energy is dissipated as heat in the resistance, but in either case considerable improvement is made by omitting the mechanical brakes. This problem is receiving active attention also, in main line railway work, and developments now in hand point to the successful solution of regenerative control in particular cases.

The central station load factor is being improved by eliminating the short time peak loads. This can be done in several ways; storage batteries will serve for extended peaks; or, where the peak load is of very short duration, a flywheel attached to the driving motor, together with the proper control mechanism, will effectually smooth out the peaks. Where the peaks last for some time, automatic devices can be used to reduce the power demand by a reduction in the speed of the motor as the torque increases. The use of field control for motors is another means of reducing the maximum power demand. The motor can be geared to its load with such a ratio as to operate the load at a speed lower than maximum and, with a strong field at the start, will develop the heavy starting torque with less power consumption than if geared for the maximum speed at the same field strength. The field of the motor can then be weakened, as the speed requirement increases, particularly where the torque required of the motor decreases at maximum speeds.

There are practically no power problems which cannot be solved by motor drive, under proper conditions, if the application engineer is in possession of the necessary information. Many of these applications have been delayed by the absence of reliable information as to the amount and distribution of the load, and many motor application failures in the past have been due to guess work in making the applications. The prejudice of power users is rapidly being overcome, however, and the general public is looking upon motors as the logical means of driving their various types of apparatus.

New applications of motors have recently been made to a number of processes in sugar mills, where the first motors are being used to drive the main crushing rolls.

In the oil well field, the work has progressed far enough to enable standard equipments to be arranged for. This is also the result of a careful analysis of the requirements and better information, which has enabled the manufacturers to eliminate many of the special devices, and to furnish a more uniform equipment which, in turn, reduces this application to a straight business proposition, instead of an experimental one.

The same is becoming true of railway apparatus. In the past, it has been the desire of each railroad man to have the manufacturers devise a special equipment for his particular use. This is true of all applications where conditions are rapidly changing and competition is keen. It has resulted, however, in increased cost of the electrical equipment and longer shipping dates. Railway men have now standardized their equipments more or less, and are beginning to see the advantages of standard equipment. This reduces the cost of spare parts, and enables their men to become thoroughly familiar with the apparatus, thus giving it better care, which improves its efficiency. If this standardization is carried out generally, it will enable the manufacturers to carry motors in stock, which will decrease the cost of this apparatus and improve deliveries. This is very noticeable in the industrial field, where standard industrial motors are available.

The use of electric welding has rapidly increased during the past year. This is particularly true in railroad shops, where the electric arc is used for repairing the tube connections in locomotive boilers, especially on the fire box end where the service conditions are very severe. The apparatus for this purpose has been greatly simplified, and now standard machines

and switchboard equipment can be used. The device is simple enough to be operated by an ordinary mechanic.

Great improvements have been made during the past year in the electric storage battery, as applied to small locomotives, automobiles and similiar work. Heretofore it has been necessary to regulate the current during charging, which has complicated the charging outfit and made it necessary for the attendant to give close attention during the charging period. It is now possible to purchase batteries which can be charged at a constant potential. This enables the battery to be charged more quickly and more economically and materially simplifies the process.

There are still many fields of application for the electric motor that have not yet been developed; these fields are waiting to some extent for manufacturers to simplify their equipment but, primarily, upon the central stations, which should be able to provide attractive rates for power, as well as for heating devices. With cheap electrical power, the use of electric motors in many operations and for a great variety of miscellaneous work now being performed by hand, will bring about the development of more convenient electrical devices for these purposes and will tend toward material improvement in the load factor of our power plants.

COMMERCIAL DEVELOPMENTS IN DETAIL APPARATUS

G. Brewer Griffin

FROM the commercial standpoint, one of the new developments of the year is the electrical equipment of gasoline automobiles. This development has not been actually confined to the past year, but while the devices were on the market during the preceding year, it is only during the last twelve months that this business has assumed commercial importance. Large numbers of outfits have been shipped during 1913 and the automobile trade at large and the buying public are rapidly coming to the conclusion that such equipments are an essential part of any high grade car. Service stations where this apparatus can be attended to in the field and instructions given to various agents of the automobile manufacturers have been established in considerable numbers.

In the meter field, the maximum demand indicating watt-hour meter has been placed on the market. Graphic meters have proven very popular for use in studying shop costs and operations and their sale is rapidly increasing.

The pressed steel fan motor met with instant success last season. Light weight and attractive appearance, accompanied by low power consumption per cubic foot of air moved, have combined to create a large demand for these motors.

There has been a marked improvement in the volume of switchboard business, although accompanied by such reductions in selling price as to greatly reduce the percentage of profit.

Oil circuit breakers which will sucessfully break the heaviest loads that have been carried by main lines, are now available at reasonable prices for use on circuits operating from the lowest to the highest voltages.

There has been a considerable increase in the types of arc lamps available. The success of the metallic flame arc lamp has been equalled by the new long life flame carbon arc lamp. The latter has been developed in a highly satisfactory commercial form. This lamp should meet all the critical demands of the operating central station men and the prospects are for a very considerable demand for this lamp during the coming year.

Vehicle battery charging rectifiers have been considerably improved, resulting in increased life in service over that of a year ago. As the electrical vehicle for pleasure and business purposes is becoming more and more popular, the field for the sale of these devices is becoming more broad. Some of the more progressive central stations are arranging to locate charging plugs at the curbs in front of residences and offices where they will be of the greatest service. The plugs are in pot-head type conduits, running into the cellar to the meter connection. By this means vehicles can be charged while not in use without the necessity of going to a charging station. Such arrangements will undoubtedly make the use of electrical vehicles still more popular.

New insulation materials have been developed to a marked degree during the past year. Machines have been developed for fabricating bakelite-micarta into various forms. Such products have a great many applications, both electrical and mechanical, and new fields are continually opening up. Such products as water and steam valve washers, small gears, insulating plates, tubes, rods and numerous other details are being made, and in every case, where properly applied, results more satisfactory than with any other known materials have been secured. The dielectric value of micarta and its non-hygroscopic qualities combined with strength and durability have made these applications possible.

Improvments in distributing transformers include improved insulation, the introduction of the highest grade steel, with machine moulded cases and the utmost care in the manufacture, inspection and assemblying of every part. Notwithstanding all of these improvements, the selling price of such transformers has been lowered.

Electric heating and cooking devices have been of great assistance to central stations as a means of popularizing the use of electrical apparatus. The prospects for a continued demand for such apparatus are very favorable. New types of irons, percolators,

saute pans and luminous and non-luminous radiators of attractive appearance have also made their appearance. In the industrial products, the new linotype metal pot heater is a most promising addition.

In overhead trolley line material and supplies, porcelain insulators, etc., there are signs of considerable business for the coming spring. Lines of apparatus have been rounded out and developed during the past year so that almost any contingency has been provided for. The demand for porcelain goods has considerably increased, and it is expected that there will be even a greater volume of business during the coming year.

While the business of the country in general has not been quite so good in the last year, this does not apply to detail apparatus and there is no indication of anything other than an ordinary falling off in the general business. It is apparent that the prospects for the next nine months will be even better than for the corresponding period of 1913. This statement is, of course, predicated upon the ability of power companies to finance themselves in their extensions of new lines, new power plants and carrying out their general business campaigns as intended.

COMMERCIAL REVIEW OF CENTRAL STATION APPARATUS

F. P. Dillon

The year 1913 has witnessed no radical departure from former practice in the development of electrical apparatus, except in one or two special cases. The trend of development has been to standardize along the line of higher voltages and greater capacities in units, following the demonstration of the successful application along these lines by actual operation. Improvements in efficiency and reliability in operation, and improvements in the methods of manufacture are ends constantly sought by the builder of electrical apparatus, and modifications in design during the year have resulted in a gradual progress in such particulars.

Turbo-Generators — In turbo-generators there has been a considerable progress in the design and manufacture of machines, and during the year a number of units ranging in capacity from 15 000 k.v.a. to 20 000 k.v.a. have been built and placed in successful operation. These units, while larger than sizes generally selected in the past, are unique, in that they operate at higher speeds, being designed for 1 500 r.p.m., 25 cycle, and 1 800 r.p.m., 60 cycle The successful performance of these relatively large units has demonstrated the adaptability and reliability of such machines.

A very remarkable development is shown by the 30 000 kw turbines, which are a product of the year's work. Three of these units will be installed in the plant of the Interborough Rapid Transit Company, of New York City. They are of the "cross-compound" type, consisting of two complete turbo-generator units of equal capacity, the high pressure unit consisting of a non-condensing turbine, direct-connected to a 15 000 k.v.a. generator, operating at 1 500 r.p.m. The low pressure unit is of equal capacity, condensing type, operating at 750 r.p.m. The "cross-compound" principle is not essentially new, even in turbo-generator practice, as there have been units built previously in smaller capacities utilizing this principle, as well as some units where two turbines have been worked in tandem driving one generator. These particular units, however, give a very simple arrangement, involving no difficulties of alignment, and the general construction and proportioning is such as to make possible the maximum economy. A Rankine-cycle efficiency of approximately 75 percent is obtainable with these units and in view of the usual performance in turbo-generators, it is readily seen that this is a remarkable result.

Water Wheel Generators—Improvements in water-wheel generators during the year have been along the lines of increasing efficiency, insuring reliability in service, and of improvements in methods of manufacture. There has been a remarkable demand for water-wheel generators, resulting in some large sizes being produced. Vertical type water wheels of 12 000 k.v.a. capacity driven by a single-runner water turbine are a feature of the year's development, and in horizontal units, generators ranging in size up to 17 500 k.v.a. capacity have been built and placed in operation.

Rotary Converters—The application of the commutating pole in the design of rotary converters has been very marked, this type of design being generally applied now to practically all 25 cycle rotary converters and to 60 cycle rotary converters of the larger capacities.

The use of 60 cycle rotary converters has been greatly extended during the year, and this apparatus has proven itself by the very successful results obtained from its operation. The units of larger sizes have demonstrated their correctness of design, and the possibility of larger 60 cycle converters is merely a question of the load conditions demanding such apparatus. There has been built during the year the largest 60 cycle converter ever constructed; namely, 2 500 kw at 500 volts. This converter will be approximately the equivalent of a 3 000 kw converter at the usual railway voltage, namely, 600 volts. In the 25 cycle converters, the year has seen nothing developed larger than that which had previously been built, but the use of large 25 cycle railway rotary converters, namely, 4 000 kw capacity, is very general, and numerous railway systems are now using units of this size which a few years ago did not have converters in excess of 2 000 kw capacity.

There has been a marked increase in the use

of high voltage rotary converters for railway work and, on 25 cycle systems, single converters are used for direct-current voltages as high as 1 500 volts. On 60 cycle systems the prevailing practice is to utilize two rotary converters operating in series on the direct-current end. No large units of the high voltage class have been installed during the year, since the electric railways utilizing high voltage in general require only smaller capacity rotary converters. Such machines are built and in operation up to and including 500 kilowatts.

Motor-Generators—Motor-generator sets are still very generally used, especially on the 60 cycle systems, and the use of a synchronous motor-generator set as a medium for improving power-factor, due to the condenser capacity of the synchronous motor, is becoming very generally accepted. For railway work, the rotary converter has demonstrated its adaptability, except in cases where it is necessary to have a considerable corrective effect for power-factor, and in such cases the synchronous motor-generator set has a field of its own.

Geared Generators—The use of direct-current generators geared to high speed turbines through the reduction gear is increasing, and there are in service a number of units of this character, the largest ones being two 3 500 kw, 270 volt, direct-current generators operating at 180 r.p.m., and connected through a ten to one gear to a steam turbine. This type of unit is particularly suitable to cases where direct-current power is required and there is available steam for driving the turbine, of the high pressure non-condensing type or the low pressure condensing type.

Transformers—The development in power transformers has been along the lines of improving insulation, increasing efficiency, and developing constructions that are mechanically and electrically rigid and reliable in service. Micarta is used to provide solid barriers affording great dielectric strength. There have been developed and constructed testing transformers capable of giving 500 000 volts, from high tension to ground. This development is one that necessarily must be kept ahead of the development of high voltage service transformers in order to obtain the requisite tests on insulation.

The outdoor transformer is being very generally supplied, and both railway companies and lighting companies are recognizing the desirability of taking on the smaller customer through the medium of outdoor transformers and outdoor sub-stations. This equipment frequently makes it possible to take on a customer whose business would not be profitable were it necessary to install an expensive sub-station housed within a building.

While there have been many large capacity high voltage transformers built during the year, the installation of fourteen 150 000 volt transformers on the system of the Pacific Light & Power Company, in California, is of special interest.

Portable and Outdoor Sub-Stations—The portable rotary converter sub-station as well as the outdoor transformer station is not a new development of this year, but its application has had a remarkable growth. The design of the portable rotary converter sub-station has been greatly simplified and cheapened, to the end that it is now within reach of practically any railway, and the experience of companies owning such sub-stations indicates that the uses to which these sub-stations can be put are manifold. The same thing applies in a great degree to the outdoor transformer sub-station, it having been standardized and developed along the line of simple, compact construction, making it readily installed and reliable in operation, and, as stated before, this particular field is one where service can be delivered to small customers economically.

Switching—The development of switching apparatus has kept pace with the increase in voltages and the increase in capacities of units, and numerous detail improvements have been effected looking to reliability of operation.

DEVELOPMENTS IN INDUSTRIAL MOTOR APPLICATIONS

J. M. CURTIN

THE progress in the application of electric motors for industrial purposes during the past year has been along conservative lines, but has clearly demonstrated the economy and utility of the electric motor. The manufacturers are realizing that the utilization of electricity is necessary where efficiency in operation is required, and commercial conditions at present are such as to require efficiency in methods of manufacture, as well as in organization, if a profit is to result. The recent tariff legislation is causing the American manufacturer to see, as never before, the necessity of using the most modern methods in order to compete with manufacturers of other countries where labor is cheaper; hence, the continuous growth in the installation of electrically-driven machinery. In practically all new industrial plants where power is required, electrically-driven machinery has been installed, notably in the textile and steel industries where, in addition to its almost universal use in new installations, the electric motor is rapidly replacing the old forms of motive power.

Steel Mills—During the present year there will be placed in operation the first electrically-driven reversing blooming mill in the United States. This installation will be watched with much interest as it as a radical departure from past practices, although non-

reversing blooming mills are now generally driven by electric motors. The results obtained from this installation will undoubtedly do much to stimulate the interest of steel companies in such equipments.

The new magnet control switches designed primarily for steel mill service should greatly aid in the application of electric motors to the severest industrial requirements. The apparatus is of very rugged construction and the control system has been very much simplified due to the use of a specially designed series type of contactor. It has recently been demonstrated that magnetic controllers are especially suitable for the hoist motion of cranes. For this purpose the controller is equipped with a dynamic braking feature, which is very useful in the lowering motion, permitting a much simpler mechanical construction of the crane and the elimination of the mechanical brake which, as a rule, requires considerable attention. This type of control is well adapted to all kinds of industrial service.

Arc Welding—The arc welding process has been brought into more general use during the past year by the introduction of a complete outfit, including motor-generators, control and switch panels, shields, pencil holders, etc. This process is being used extensively for repairing fire boxes and engine frames, for flue welding, etc., in railway shops and for general repair work for steel and iron castings in machine shops.

The Textile Industry—Activity in the textile industry has been curtailed to a great extent pending the tariff legislation, only such developments being carried on by the mills as was absolutely necessary. Several new cotton mills have been built in the South and numerous changes in equipment made in the Northern mills. It is noteworthy that electric power is used as a means of drive in all the new mills One of the chief reasons for giving more careful attention to individual drive has been the development of the feature on looms whereby the empty bobbin is automatically ejected and the filled bobbin placed in the shuttle. This automatic feature increases the cost of the loom considerably over the cost of a plain loom, thus making the percentage cost of the individual motor much less than in the case of the plain loom and, on account of the increased production, it is more economical to install individual motor drive than to purchase the additional machinery to obtain this same increase, a condition which does not always exist with plain looms. Brass tubes have also been introduced for the cylinders of the spinning frames, thus permitting an increase in speed of approximately fifty percent with the spindle speed the same. This permits the use of a higher speed motor for individual drive, thereby decreasing the cost of the motor, and the increased production makes this a very popular method of drive. The impression prevails that business will be more active in the textile industry during the coming year and that electric drive will be more extensively used than ever before, since the tariff reduction will cause the mill owners to install the most economical method of drive in order to reduce operating expenses.

Pumping Installations—A year or so ago there was a marked trend toward higher speed for centrifugal pumps for general service. This tendency is no longer so pronounced and there appears to be a more general appreciation of the fact that a very high speed, light weight unit is not necessarily the most desirable nor the least expensive. The installation of very large central pumping plants for irrigation has not been so marked as in previous years due largely to the slow development of the tracts already so supplied. There is no question as to the ultimate success of most of these projects, but considerable educational work is necessary before some of the arid lands are thickly settled. The increase of small individual plants for irrigation has, however, been little short of marvelous. The demand which existed several years ago for cheap outfits has turned in favor of better machinery with higher efficiencies, giving less operating trouble and lower operating costs. It is worth noting that, where electric power can be purchased, the distillate engine is seldom the competitor of the electric motor. A tremendous increase in the installation of small electrically-driven individual pumping plants only awaits the extension of the power lines, as there is still an immense acreage which can be reached by reasonable extensions of present systems.

Mining—In the mining field, the self-starting direct-curent motor in capacities up to 20 horse-power, has made a distinct place for itself in the driving of mine drainage pumps and to some extent in driving small mine fans. This type of motor has a comparatively heavy compound field winding, with commutating poles, and is designed to be started by connecting directly to full voltage. No-voltage protective devices and automatic starters are not needed and the necessity for manually starting a pump or fan after failure of voltage is eliminated. The increasing use of motor-driven compressors, particularly in metal mines, has demonstrated the superiority of this type of machine where power is available either from central stations or from privately-operated plants where standby losses are reduced to a minimum. One of the principal advantages is the ease of locating the compressor stations near the application of the air, thus, reducing the transmission losses in the air system.

Small Motor Applications—The increase in the use of small motors during 1913 has been quite general. As has been the case for several years, the principal demand comes from the manufacturers of motor-driven machines, rather than from the actual users of the motors, though the activity of central stations and electrical dealers has greatly increased the latter ave-

nue of consumption. Portable electric tools of all kinds have come extensively into use in the manufacture and repair of automobiles. Electric drills and bench grinders have been particularly popular, due to the fact that they are actual savers of time and labor. With numerous garages, both public and private, springing up in various parts of the country, the use of small motor-driven tire pumps and pressure pumps has become quite general. The popularity of moving picture shows has materially increased the demand for small motor-driven machines. Most of these are equipped with motor-driven moving picture machines, motor-driven piano players or other musical instruments and motor-driven ventilating equipment. Among those machines for use in the office and home, the vacuum cleaner still remains very popular although the demand has been divided more clearly than ever before between small high-speed portable machines and the larger stationary plant equipment. Such a division is entirely logical, for the stationary plant is now considered in a class with heating, ventilating or plumbing equipment. The desire of the manufacturers of portable vacuum cleaners has been of course to make these as simple, light and convenient as possible, and their activity has been to develop a machine which is suitable only for light work and which does not necessarily compete at all points with the stationary plant equipment. Motor-driven washing machines have been greatly simplified in their construction and design, and lower prices have been the rule. In office equipment the principal increase has been along the lines of adding machines, copying machines, motor-driven typewriters, mailing machines, etc.

From the point of view of the manufacturer four features are distinctly noticeable during the past year:—

1—A much closer analysis is being made by manufacturers of small motor-driven machines into questions of application of motors to the driven machine. Thus, the large purchasers have become not only exacting as to the characteristics of the motors purchased, but have come to adopt motors really better suited to the work.

2—In general, a number of improvements have been made in the operating mechanisms of small motor-driven machines which have resulted usually in the use of a somewhat smaller motor and also in the much more successful operation of the entire unit.

3—With the increase in the demand for small motor-driven machines generally, the relative increase is greater upon those using the smaller and consequently, cheaper motors. This has increased the demand for motors of smaller capacities.

4—A number of refinements in the design and construction of small motors has greatly increased their utility, adaptability and reliability in operation.

The year 1913 has emphasized the tendency toward centralization in generating electricity and instead of the comparatively small isolated electric plant of a few years ago, the industrial user of electricity is now usually a purchaser of central station power. This is especially true in regard to the mining field where large central station developments have been made in West Virginia and Alabama to supply power principally for mining purposes. The central station is thus a most important factor in the industrial developments of the present day.

PROGRESS IN RAILWAY APPARATUS

G. M. Eaton

THE striking event of the year 1913, in railway activity, is the electrification of a mountain grade on a trunk line using locomotives equipped with phase converters and polyphase induction motors designed to operate on the single-phase system. The adoption of this type of motive power by the Norfolk & Western Railway Company for their Elkhorn-Bluefield grade constitutes a turning point in trunk line electrification. This arrangement is now generally recognized as the logical means for moving mountain freight.

Double truck locomotives, between 25 and 65 tons total weight, have been standardized for 600 volt direct-current service. The first 1 200 volt high-speed passenger locomotive ever built was put in service this Fall on the Pacific coast. The use of locomotives for passenger service on interurban roads is also an important innovation. This is contrary to all previous electrification doctrine, but under certain circumstances is undoubtedly justifiable.

The extremely satisfactory performance of the small-wheel light-weight cars for city service has resulted in a great extension of their application. A line of motors consisting of a 30 horse-power motor for 24-inch wheels, a 40 horse-power for 26-inch wheels and a 45-50 horse-power for 28-inch wheels has been developed to meet the increasing popularity of this class of rolling stock. In these small-wheel cars the body is, in some cases, so close to the rail that no equipment can be installed under the floor. Special control equipment has, therefore, been developed for this class of cars, being particularly applicable where such cars are intended for multiple-unit operation. This control consists essentially of a pneumatically-operated commutating switch and line switches. The space occupied and the weight are both very small.

During the year large orders for field control motors and equipments have been placed in New York, Chicago and elsewhere.

The commutating pole mine motors continue to give satisfaction in their field. The rugged bronze sleeve armature bearings with oil and waste lubrication have given perfect performance, and there is a marked decrease in the tendency to experiment with other types of bearings in mine service. The cast steel bar frame has proven thoroughly satisfactory for mine locomotives and is the most practical and serviceable frame yet developed.

The application of storage battery locomotives has advanced rapidly, due to the remarkable improvement in storage battery construction. The present day battery may be worked harder and it will withstand successfully the severe mechanical shocks incident to locomotive operation. Also, storage batteries may now be charged efficiently at very high rates and, therefore, in short periods of time, so that a battery locomotive of relatively light weight and small cost is now available. The improvement proved to be an incentive to the motor designers, so that there are now available traction motors suited particularly for operation from storage batteries.

A new method for securing axle bearing brasses has been devised by which dowels, keys and all seperate pieces have been eliminated. Forged gears have been widely applied. Their use has called still further attention to the previously recognized advisability of omitting the gear key, and a considerable advance has been made in this direction. Heat treatment of gears and pinions has been given much study and various new alloy steel gears and pinions have been developed. Flexible gears have been developed to a point where they are thoroughly practical for heavy high speed interurban car service.

A new pantagraph trolley with two separate contact shoes has been developed. This trolley is adapted for the collection of heavy current at both low and high speeds. It has been installed both for high speed passenger work and in semi-industrial yard electrification. In this latter service, where operating voltages higher than 600 volts are hardly justifiable, this trolley is used in connection with overhead construction of moderate cost, where the main line track has standard catenary construction, and where the sidings have a modified form of direct suspension.

During the past year there has been a general healthy activity in trunk line electrification, many important grades being made the subject of study, and the outlook for the future of such electrifications seems promising. The single-phase system has been given a great impetus in connection with these trunk line grade electrifications, as the demand for far more powerful locomotives than any yet built is proving this system to be the only practicable solution of the electrification problem.

RECENT DEVELOPMENTS IN INDUSTRIAL TRAINING

C. R. DOOLEY

INDUSTRY has long felt that despite the excellent work being done in the development of our national educational institutions, the result has been unsatisfactory. During the past ten years, in a very quiet way, a surprising number of industries have established their own training schools, and today the educational department is a recognized part of a progressive corporation. Each company has developed its own method. Until recently there has been practically no attempt at coöperation or a systematic exchange of ideas and experiences. Consequently there has been a great deal of needless duplication of experiments and mistakes.

Early in the past year the obvious thing happened. A few business men got together and found that they had many problems in common in the development and training of their men. The suggestion of a means of exchanging ideas was hardly made before it became a movement, and within a few months took definite form in the establishing of the National Association of Corporation Schools Forty-four corporations now compose the active membership, and the mere diversity of these industries is significant of the comprehensive scope and the great possibilities of the movement. This assocation is not in the least antagonistic to the established educational institutions. In fact, it is believed that some day these institutions will provide a very large part of the training which the various industries require. In the meantime some definite action must be taken. The industries themselves must set the standards.

Last September the association held its first annual convention, where more than 65 industries were represented by 127 delegates. This meeting was epoch-making and remarkable for its spirit of perfect harmony and serious purpose, as well as for its breadth of view. The speakers told simply what they were doing; under what conditions they were working; what success they were having, and something of their plans for future development. No one boasted of his achievements; no one sought to exploit his own ideas; no "sure cure" plan was proposed, but each spoke simply to add his experience to the collection of data, more with a desire to receive suggestions than to give advice. The discussion was one great round table of exchange of ideas, much more free from prejudice than is usually found at educational meetings.

Many varieties of industries were represented, and all phases of specific training in salesmanship, engineering, management and industrial trades, in addition to such subjects as the health of the individual, sanitary factory conditions and community welfare were discussed. Interest centered about the happiness of the individual employe, as both a moral and an economic factor in industrial progress. Only that kind of welfare work which has economic value behind it and which, therefore, is more rightly called educational work can accomplish the desired results; and also, only that business organization can hope to succeed in the future which has for its highest motive the happiness and highest development of the individual employe. Efficiency systems which neglect the element of humanity will fail absolutely.

It has now been some ten years since the New York Central Railroad and the Santa Fe established

their industrial training work for mechanical trades apprentices. During this period this particular kind of company school has been so well developed that the establishing and conducting of such schools is now largely a problem of administration rather than of method. It is true that there are yet many industries in which the methods have not been at all standardized and in which the basic conditions have not yet been thoroughly analyzed; however, on the whole, the trade teaching end of industrial training as conducted by corporations has been very well worked out.

Attention is now being turned, on the other hand, to the larger phase of the subject, the training at the other end of the line—namely, the education of the executive. Very recently the statement has been made by half a dozen managers in different industries, that they did not have an executive who knew his own job thoroughly enough to train his assistants properly. It is rapidly becoming a prime duty of an executive to instruct and train the men of his staff. This means that industrial training should begin at the top; that the big boss must go to school, and that those best equipped to teach are those actively engaged in the work, though they have yet to be developed into teachers. Before we can hope to develop young men properly trained in the simple phases of industrial work, we must develop executives and department heads who have such a clear vision of their functions and fields of work; who have such a comprehensive grasp of their positions and responsibilities; who know so thoroughly the details and also their comprehensive relations; who have so standardized their jobs, that they in turn can at least give direction to the training of those under them. Present day executives and managers just "growed, like Topsy." In the future they will be especially selected and specifically trained.

A very important department store owner and manager of Boston at a recent meeting of the directors of the Association of Corporation Schools, said: "My job is to educate myself thoroughly by studying the organization and management of department stores throughout this country and Europe. My next job is to hand this information, or education, if you please, down to my department heads, who in turn hand it down to the buyers, the sales force and so on down to the engine room attendant, and in this way fill all positions by men especially trained for them rather than by the present method of chance or circumstance."

This is perhaps the most significant phase of all of the many developments which are coming about in the field of industrial education.

An idea of the comprehensiveness of this movement may be gained by referring to the appended list of industrial organizations which are members of the National Association of Corporation Schools.

Addressograph Co., Chicago, Ill.
American Locomotive Co., Schenectady, N. Y.
American Multigraph Sales Co., Cleveland, O.
American Telephone & Telegraph Co., New York, N. Y.
Atchison Topeka & Santa Fe Railway, Topeka, Kan.
The Brighton Mills, Passaic, N. J.
The Brooklyn Union Gas Co., Brooklyn, N. Y.
Burroughs Adding Machine Co., Detroit, Mich.
Cadillac Motor Car Co., Detroit, Mich.
Carnegie Steel Co., Pittsburgh, Pa.
Commonwealth Edison Co., Chicago, Ill.
Consolidated Gas Co. of New York, New York City, N. Y.
The Curtis Publishing Co., Philadelphia, Pa.
Dodge Manufacturing Co., Mishawaka, Ind.
Doherty Operating Co., New York, N. Y.
R. R. Donnelley & Sons Co., Chicago, Ill.
Thomas A. Edison Co., Orange, N. J.
General Electric Co., Schenectady, N. Y.
Haines, Jones & Cadbury Co., Philadelphia, Pa.
The Larkin Co., Buffalo, N. Y.
The Lunkenheimer Co., Cincinnati, Ohio.
The Manhattan Rubber Mfg. Co., Passaic, N. J.
National Cash Register Co., Dayton, O.
National Cloak & Suit Co., New York, N. Y.
The New York Edison Co., New York, N. Y.
Norton Company, Worcester, Mass.
Packard Motor Car Co., Detroit, Mich.
The Pennsylvania Railroad Co., Altoona, Pa.
Plymouth Cordage Co., Boston, Mass.
Public Service Corporation of N. J., Newark, N. J.
M. Rumely Company, LaPorte, Ind.
Spencer Trask & Co., New York, N. Y.
The Spirella Co., Meadville, Pa.
The Stanley Works, New Britain, Conn.
Strawbridge & Clothier, Philadelphia, Pa.
Travelers Insurance Co., Hartford, Conn.
Remington Arms Union Metallic Cartridge Co., N. Y.
Trow Directory Printing & Bookbinding Co., N. Y.
United States Cast Iron Pipe & Foundry Co., Burlington, N. J.
Western Electric Co., Chicago, Ill.
Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.
Westinghouse Machine Co., East Pittsburgh, Pa.
Willys-Overland Co., Toledo, O.
Yale & Towne Mfg. Co., Stamford, Conn.

ELECTRIC PLEASURE AND COMMERCIAL VEHICLES

BERNARD LESTER

SINCE the electric vehicle is primarily simple in its construction and operation, the improvements made have been more in the way of refinements than the application of new principles. The increase in demand has largely been along the line of commercial trucks. As such a vehicle is employed only for utility and the advantages obtained by its use are subject to detailed analysis upon a dollars and cents basis, it has been employed to a greater extent by the leading companies engaged in transportation and distribution of goods such as express companies, breweries, bakers and department stores than by any other classes of users. As could be expected the larger the number of these vehicles placed in service, the lower are the operating expenses. Fortunately a careful study of the comparative merits of electric commercial vehicles and gasoline commercial vehicles has been made by several companies who have employed both types of vehicles, results of which have served generally to exploit the use of the electric com-

mercial car. The number of sizes and types of electric commercial vehicles has increased to a considerable extent and there has been a specialization of these vehicles for certain definite purposes, such as service trucks for use by central stations and power companies, ambulances and similar types of service.

A number of refinements in the construction and finish of electric pleasure vehicles have materially improved their appearance and utility. A greater mileage has been obtained by improvements in the construction of the chassis and the use of batteries of thinner plates and a larger number of plates per cell. Improvement in the design of vehicle motors has resulted in an increased operating efficiency and consequently a material saving in power to the user. Dual or duplex control has been adopted by a number of manufacturers of electric pleasure vehicles. In this way the car can be operated either from a front seat or from a rear seat. In some cases automatic control has been employed, though this has not been generally adopted. The use of single reduction worm drive is being exploited as a distinctive feature on some of the latest types of vehicles.

If anything, greater advance has been made along the line of simple, efficient and reliable apparatus for use in charging electric vehicles than during any year previous. The number of electric pleasure vehicles and commercial trucks which have been put into service have brought about a realization of the absolute necessity of a close analysis of the problem involved in charging electric vehicles. A number of garages, both large and small, have equipped themselves especially for this class of work. Systems have been worked out for handling cars in quantities efficiently and keeping a definite record of their condition and of the work done upon them.

Mention should be made of the active work carried on by the Electric Vehicle Association of America. On October 27th and 28th at Chicago, the annual convention was held, at which reports were made of work done during the past year by the various committees and work proposed for the future. This Association has been carrying on a very active campaign with the public in the interest of the central stations, manufacturers of electric vehicles and manufacturers of their component parts, by means of advertisements in the popular magazines and through other channels. Two complete and attractive publications have been issued, one upon the pleasure vehicles and the other upon the commercial truck. The Association at the present time serves as a center of coöperation for all those interested in this enterprise.

TRANSFORMER PROCESS

W. M. McConahey

WHILE 1913 has been a year of great activity in transformer manufacture, it has not been productive of any new types or of any radical changes in the methods of design or materials of construction. In fact, transformers seem to have reached that stage in their development where changes will come more slowly and will be more in the nature of detail improvements rather than wide departures from previous standards. We have added considerably to our knowledge of the properties and characteristics of the materials used in building transformers but the extent of this is apparent chiefly to those directly connected with design.

During 1912, work was begun on the first 150 000 volt transmission system. This system is now operating to a limited extent so that 1913 has the distinction of seeing the first 150 000 volt power line in commercial use. Successful operation at this voltage seems to be assured and there is no apparent reason why we cannot go higher provided there is promise of sufficient return on the investment.

The placing of transformers in outdoor sub-stations has been greatly extended. At first only small units of medium voltage were used but the saving effected by placing transformers out doors soon became apparent and now there are many outdoor sub-stations containing large transformers of high voltage. Self-cooling transformers are peculiarly suitable for such service since they require no attendance. The outdoor sub-station is responsible for the greatly increased use of this type in large sizes.

The same tendency towards higher voltages which we have observed in power transformers is also to be seen in distributing transformers. A few years ago there were very few distributing transformers operating at voltages above 4 000 but this limit has been increased gradually by successive steps until now they are operating on circuits as high as 19 000 volts.

Thus we see that everywhere the tendency is towards higher voltages, and a little reflection shows that this is to be expected. The field of electrical service is broadening out and taking in territory farther and farther away from the generating stations which, for reasons of economy, should be few and centrally located, rather than many and scattered.

DEVELOPMENTS IN INDUSTRIAL ENGINEERING

J. M. Hipple

THE past year marked the close of one of the recurring periods of redesign of industrial apparatus. For four or five years, manufacturers have been more than ordinarily active in developing new lines of apparatus and there are now available practically complete lines incorporating the latest results of the designer's art. There have been a number of notable developments that have made this general redesign imperative. For instance, the commutating pole, used at first for adjustable-speed motors only or as a cure for trouble in constant-speed motors and generators, soon proved its right to be considered as a prime factor in the

design of direct-current machines of all types. As a result complete lines of constant-speed, commutating-pole motors for general industrial service and varying-speed, commutating-pole motors for mill and hoist service, are now on the market.

Great advances in the use of rolled and pressed metals in other industries indicated their probable usefulness in motor construction. Following out this line of development, complete lines of both alternating-current and direct-current motors up to approximately 150 horse-power are available in which strength, rigidity and light weight have been secured by the use of these materials in motor frame, bearing brackets, brushholders and details. The development of commercial methods of casting end rings on the rotors of squirrel cage motors has led to new designs in which the old bolted-on construction of ring to bar has been discontinued. The cast on ring makes a great advance in rotor construction and results in a practically indestructible rotor.

In the small motor field, below one horse-power, the development of commutator motors that will operate successfully and at approximately the same speed on either alternating or direct-current circuits has greatly simplified the marketing of vacuum cleaners, portable electric tools and similar devices.

Two developments have shared in bringing about a great advance in industrial motor control design. These are: bakelite insulation in its various forms, of moulded and bakelite micarta; and the introduction of the self-closing or lockout switch. The introduction of bakelite materials has made possible entirely reliable control insulation that will withstand the heat, moisture and rough usage to which control apparatus is subjected. The use of series self-closing switches has made it possible to take the majority of the interlocks off the control panel, thereby reducing the wearing parts and greatly simplifying the entire controller. The simplicity and reliability of the new lines of automatic control have greatly increased its use in all classes of service. In the steel mill industry automatic control is being used practically throughout. Even the traveling cranes, which until recently were equipped with hand control, are now being equipped generally with automatic control. The same condition prevails in the machine tool industry and, in fact, wherever flexibility, convenience and safety are essential features of operation.

In addition to the developments mentioned above, leading to redesign, there has come with the redesign a development of manufacturing processes and a more careful study and selection of materials which has resulted in better balanced designs.

In a corresponding review a year ago, the subject of electric starters for gasoline automobiles was mentioned. Since that time developments in this line have been very rapid. The electrical equipment of gasoline automobiles consists of three main features: ignition, lighting and starting. Developments of the past year have been in devising various methods of providing these features in a car, either separately or in combination. Many poorly designed machines and makeshift applications have been put out upon the market and the electric equipment of the car has been discredited by just so much. In spite of this, the demand for electric equipment covering all three features has become practically universal. While no standard has yet been reached, there seems to be a decided sentiment in favor of combining the ignition, lighting and starting functions in two units, preferably ignition and lighting in one unit and starting in a second unit. Such a combination is along rational lines from the standpoint of design of the machine and also works out to best advantage as regards application to the engine. The elimination of the poorly designed sets and makeshift applications has already begun and it is confidently believed that another year will see this situation placed on a much more stable basis and that the manufacturers, realizing the reliability of electrical equipment, will be led to install additional electrical devices.

ENGINEERING TENDENCIES IN GENERATING APPARATUS

F. D. Newbury

THE notable feature of the year 1913 in the field of larger generating apparatus has been the phenomenal increase in the number of extremely large steam and water turbine-driven generators applied. This has been due to the ability of the manufacturers, on the one hand, to supply such larger units; to their economy in first cost of apparatus, real estate and buildings, and economy in operation; and finally, on the other hand, to the favorable business conditions during the latter part of 1912 and the early part of 1913 that made their purchase possible. Considering only the largest work of this kind done in the past eighteen months by the company with which the writer is most familiar, twenty-one water wheel driven generators have been completed or are under construction having an average capacity of 13 500 k.v.a. and a total capacity of 283 500 k.v.a. During the same period, twenty-five steam turbine units having an average capacity of 18 000 k.v.a. (and a total capacity of 450 000 kv.a.) have been completed or are under construction. The significance of these figures is realized when it is known that previous to this period only an occasional 10 000 or 15 000 k.v.a. unit was built. In this same connection it is interesting to note the preponderance of steam turbine-driven units over alternating-current generators driven by all other prime movers. The "boom" period previous to the

one from which we have apparently, just emerged occurred in 1906-7. Comparing outputs for equal times in these two periods, representing maximum production for each class, it was found that during 1906-7, 214 000 k.v.a. of turbo-alternators and 293 000 k.v.a. of all other alternators were built; while in 1912-3, 520 000 k.v.a. of turbo-alternators and only 420 000 k.v.a. of other alternators were built.

In the previous period, turbo-generators represented somewhat less than half of the total for the selected period, while in 1912-13 turbo-generators passed the total of all other alternating-current generators and represented 55 percent of the grand total. While turbo-generators increased nearly 150 percent, all other alternating-current generators increased less than 50 percent. While these figures are taken from the business of only one company, they confirm a general impression and are, undoubtedly, typical of the business of the country.

It is also interesting to consider, briefly and in general terms only, the differences, other than in amount, in the apparatus built during these two periods. Four general tendencies may be noted; increase in size of individual units; increase in speed of the largest units; increase in the use of higher frequency apparatus; and increased refinement and complication in design to meet the wider duty and better performance demanded of electrical apparatus.

The largest units have tripled in size during this period; where 10 000 k.v.a. units were unusual in 1906-7, and in fact, were unusual for three years thereafter, 20 000 k.v.a. units have been common, and 30 000 and 35 000 k.v.a. units have been under construction in 1913. The so-called "cross compound" 30 000 k.v.a. units being built for the Interborough Rapid Transit Company mark a new development in power unit design and a new record for guaranteed economy.

Steam turbine speeds have increased from 720 and 750 r.p.m. for 25 and 60 cycles generators to 1 500 and 1 800 r.p.m. for units of double capacity. The capacity of 3 600 r.p.m. units has increased from 1 000 k.v.a. to 5 000 k.v.a. In rotary converters, to mention a class of apparatus in which speed is determined solely by the electrical apparatus, a 2 000 kw 600 volt, 25 cycle converter, the largest built in 1907, has increased in speed from 187 to 375 r.p.m. in 1913. Also in 1913, 4 000 kw units at 187 r.p.m. have been placed in operation. The speeds of 60 cycle converters have increased as markedly and, it is worthy of note, with decided improvements in operating performance.

The relative increase in the use of 60 cycle apparatus has been striking. In 1907 the largest machines —both steam and water driven—were associated almost entirely with 25 cycles. In 1913 the lower frequency apparatus has been decidely in the minority. Fifteen out of the twenty-five large turbo units previously mentioned were for 60 cycles or higher; out of the 21 water wheel units that were mentioned only one was for 25 cycles. In this same connection the greatly increased use of 60 cycle rotary c[illegible] as compared with 25 cycles, is worthy of note. Since 1909 there has been an entire reversal in position of the smaller 25 cycle and 60 cycle rotary converters. While in 1909, 300 and 500 kw 25 cycle converters were commonly used and these sizes of 60 cycles converters occasionally used, the reverse has been true in 1913. This can only mean that operating companies are satisfied with 60 cycle converters. The development of the 60 cycle converter since 1909 as an entirely dependable piece of apparatus has opened the railway field to central stations, generating 60 cycle power, and has enabled such stations to follow the lead of the large 25 cycle stations in the use of rotary converters of the booster type to supply direct-current lighting circuits. The significance of these facts in pointing to the great extension in the use of central station power and in use of rotary converters by central stations is apparent.

Electrical apparatus seems to be no exception to the general law that development and a more complicated structure go hand in hand. The period under consideration has seen the addition of commutating poles to commutating machines in general, including generators, motors and rotary converters; the great extension of rotary converters of the booster type for variable voltage circuits; the greater use of compensated direct-current generators for railway and rolling mill work; the necessarily increased complication of cores and windings of the largest turbo-generators. All of these changes have good reasons back of them and have resulted in improvements in operation, as otherwise they could not persist; at the same time they have greatly increased the skill required in design and in manufacture to maintain a satisfactory standard of product.

ENGINEERING DEVELOPMENTS IN DETAIL APPARATUS

T. S. PERKINS

A REVIEW of the tendencies and progress in 1913 indicates a continued effort to further perfect and simplify the apparatus which already covers rather broadly the field of application. Comprehensive lines of apparatus covering most of the requirements, with a few notable exceptions, are already on the market and the tendency has been to make them more suitable, particularly with a view of increasing and extending the use of electrical energy.

Electric Lighting—Unusual activity has marked the lighting industry in the past twelve months. Each development in the line of more efficient apparatus has stimulated the extensive movement for more and

better light, which has included the small towns as well as the large cities. The long burning flame carbon arc lamp in particular has been developed to such a degree that its commercial success as a high power, high efficiency lighting unit is well established. Not only is this true of the pendant type of lamp, but the unusually high efficiencies and illuminating qualities of the flame carbon unit have lead to the development of an ornamental pillar type long burning flame carbon lamp. The well established commercial returns which have followed the installation of the so-called "white ways" make it seem certain that, with the unsurpassed ornamental qualities of this lamp, a new record will be established in the direction of intense and efficient lighting which is at once artistic and scientific.

Also the metallic flame lamps have had no small share in the widespread move for better illumination. The movement to make the appearance of street lighting apparatus more ornamental has been shown in the development of concealed wiring street hoods and ornamental brackets for tungsten lighting. These units taken in connection with the improved efficiencies of tungsten lamps now provide a very satisfactory source of illumination for small towns and suburban districts where a high intensity is not required.

Measuring Instruments—In general, it may be said that in 1913 besides improving the quality of previously developed high grade lines, considerable attention has been given to producing, in addition, lines of instruments for service where the cost of the highest grade is not permissible, and where accuracy is not as essential as low cost. There has been an increasing application of the smaller or seven-inch size of switchboard instruments, and it is now generally used instead of the nine inch. The black dial with white letters and white pointers has been very well received and is growing in popularity.

Relays have received a great deal of attention and study in the past year. The tendency has been towards relays susceptible of accuracy in setting of time element and thus the induction type is winning favor over the bellows type. A torque compensator has been developed which gives excellent time curve characteristics to the induction relays, allowing selective setting of circuit breakers so as to isolate any defective part or section, without interfering with the operation of circuits which are in good order. The whole subject of relay protection is being placed on a more scientific basis. In applying relays, a careful study is made of the various factors in the circuit and relays are applied which give the required selective action.

In connection with new types of meters, a great deal of attention and study has been given to the subject of rates for electrical energy. One of the famous papers on this subject was by Mr. Henry L. Doherty, as early as May, 1900, in which he pointed out the logic of working to the end of making rates on a demand basis. At the present time, this is generally recognized and demand meters are beginning to be introduced. The development of such a meter has proven to be a very difficult problem, but meters of both the indicating and graphic recording types are now being exhibited and it is generally recognized that this is the proper basis on which to determine rates. The field for the indicating instrument is on small loads which would not justify the use of the more expensive graphic type of meter. The 1913 Report of the Meter Committee of the National Electric Light Association discusses this subject and describes some of the work that has been done on devices of this kind. One of the meters described is particularly interesting in that no clock is used, thus reducing the complication and increasing the reliability and durability.

Fan Motors—The drawn steel construction referred to in last year's review has met with great favor. A new finish has been perfected for these fans, giving a dull black effect which is pleasing in appearance and durable. There is an increasing use of the low speed, six blade, quiet running fan for residences where even slight noise is objectionable.

Heating Apparatus—The tendency has continued to be towards making plain serviceable devices at prices which will attract a large number of buyers. These devices offer a most promising way to increase the central station load, and make up for the loss of load due to the introduction of the high efficiency incandescent lamp.

Rectifiers—The standard types of rectifiers have had few changes made on them during the past year. The number of electrical vehicles in use continues to increase, especially commercial vehicles, and the tendency continues to be towards the use of larger batteries. The vibrating type of rectifier has continued active in its field of ignition battery charging, and special outfits have been made, up to 30 volts capacity.

Lightning Arresters—The electrolytic arrester remains the best and most used arrester for high voltage and large power installations. No material changes have been made in it, but there has been an increase in the use of charging resistance. During the past year, electrolytic arresters were built for 165 000 volts. Choke coils have been changed to reduce their over-all dimensions and to make them adaptable to either upright or inverted mounting. For high voltage direct-current railway service, the condenser type of arrester has continued to make a good record.

THE YEAR'S PROGRESS IN MAZDA LAMPS

W. H. Rolinson

THE Year 1913 has witnessed the continued improvement of Mazda lamps from the standpoint of economical light production as well as in the development of new types. The drawn wire

tungsten filament with its characteristics of pliability and ductility has made it possible to coil the wire into helical springs, thus concentrating the filament into small areas of high intrinsic brilliancy, resulting in rugged and economical lamps for such lighting service as automobiles, locomotive headlights, stereopticon and other similar requirements.

Continued experiments with various bulb blacking preventives and the introduction of such chemicals in lamps of more usual sizes has made possible the operation of Mazda lamps at higher filament temperatures and therefore higher efficiencies, so that satisfactory commercial lives are obtained at watts per candle values ranging from 0.9 to 1.14 in the sizes of 25 to 500 watts in the 100 to 130 volt range.

Improvements in the filament drawing process have made it possible to manufacture wire almost to exact sizes, so that by mechanical accuracy in wire dimensions such as length and diameter, it is possible to forecast the rating of Mazda lamps within limits of two to three percent without difficulty. The production of lamps by such methods provides lamps more closely rated in voltage and watts per candle value than it was possible to obtain by the usual commercial factory photometric process of previous years. Photometric measurements of lamps now serve the purpose of checking previous manufacturing processes. The ability to duplicate given filament sizes has made possible the standardization of lamps of comparatively small sizes for service in series electrical circuits, such as in street cars. Lamps of this character have proven successful in many installations, providing better illumination and a greatly decreased cost for power with very satisfactory service lives.

The most marked advancement of the year is the introduction of the Mazda lamp in which inert gases are present in the previously evacuated bulb. Such lamps, as have been developed, are principally of the large candle-power sizes, 500 and above, operating at efficiencies of 0.7 to 0.4 watts per candle. It is expected that this improved process will be incorporated in the standard street series types of lamps of the 60, 80, 100, 200 and 350 candle-power sizes at efficiencies ranging from 0.6 to 0.8 watts per candle, and such other lamps in which filament sizes are comparatively large or in which concentration of the light source can be made without detriment to the service requirements.

The improved Mazda lamps, in which nitrogen has been introduced, have in addition to providing means of improving enormously the efficiency of the light source, made further progress in the delaying of bulb blackening, as well as changing the location of the discolorations. The inert gas (Nitrogen), becoming heated through contact with the incandescent filament, flows upward in the bulb carrying the evaporated particles of tungsten to the base end of the lamp when the lamp is burned tip downward, thus locating the area of discoloration on a portion of the lamp bulb on which it has very little detrimental effect. Thus, superior candle-power maintenance will be found in the improved Mazda lamps.

An interesting feature of the new Mazda lamp is the extreme brilliancy and whiteness of the incandescent filaments brought about by the greatly increased temperature at which the filament operates. The new Mazda lamp operates at about 2 700 degrees C. while the standard Mazda lamps operate at about 2 300 degrees. The color value of the new lamp closely approximates daylight values and, as such, is sure to be a strong competitor of the intensive direct-current carbon arc lamp which has held almost exclusively the field requiring an illuminant under which colors may be matched accurately.

An interesting resume of the strides made in economy of light production is given below:

Type of Lamp	Candle-power per Watt Input
Carbon	0.3 Candle-power
Metallized	0.4
Mazda	1.0
" (inert gas)	2.0

Thus the Mazda lamps of the earlier part of 1913, giving more than three times as much light as the older carbon lamps, are superseded at the end of the year by lamps giving approximately seven times as much light per unit of energy. Speaking for the year 1913, the improved Mazda lamp has practically doubled the light production per unit of energy, over the most efficient lamp available a year ago.

The progress for the year has added considerably to the range covered by incandescent lamps so that there are now available Mazda lamps of candle-power values from less than one to approximately two thousand, with possibilities of extending this range materially, and of all commercial voltages from one to 260 volts. The present range of Mazda lamps includes lamps suitable for flashlights, miniature decorative purposes, automobiles, signs, railway trains, residence lighting, street railway cars, locomotive headlights, street lighting, stereopticon service and lamps large enough to be suitable for illumination of large exteriors, such as train sheds and principal business thoroughfares.

The Engineering Evolution of Electrical Apparatus—I

THE BEGINNINGS OF THE ALTERNATING-CURRENT SYSTEM

CHAS. F. SCOTT

One of the features of the JOURNAL *for the year 1914 is to be a group of articles outlining in reminiscent style, the history of the electrical industry. They will review the important steps in the development of various types of apparatus, indicating the important changes which have taken place and pointing out the engineering reasons why they were considered advisable. These articles, prepared by prominent engineers who have been in the fore-front in electrical progress, will naturally be, to a certain extent, of a personal nature and will thus have the feature of human interest as well as technical accuracy.—(Ed.)*

HISTORY may be abstract, or it may be concrete and personal; it may record events simply as facts, or it may show a continuous sequence of cause and effect. Electrical history is high-speed history. Men still live who were boys when Faraday discovered the principles of electromagnetic induction, the basis of nearly all that has followed. In the fifty years since the ring armatures of Gramme and Pacinnotti, and the drum armature of Siemens were invented, have come our dynamos and motors and our electric light and power systems. Nearly everything electrical that we have today has come from forms that were crude and elementary a generation ago or from inventions then unknown. It is a wonderful picture—this moving picture of some thirty years of electrical progress. The successive types of generators and motors, of transformers and meters and lamps, of circuit breakers and lightning arresters, of insulators and transmission lines have not come haphazard; they are forward steps to overcome difficulties or to meet new demands; there has been logical succession and true evolution. Nothing can be more impressive and instructive than to trace this development and to bring into a few pages the story of the development of a turbo-generator or a wattmeter, for example, from its prototype of a score of years ago.

Electricity was demonstrating its commercial usefulness in the early eighties; an electric car thirty years earlier, and arc and incandescent lighting, shown by Davy seventy years earlier, had been operated by costly batteries and had lain commercially dormant awaiting cheap electric power. The dynamo was brought to usefulness in the preceding decade. Edison's incandescent lamp with high resistance carbon filament came in 1879. A new problem was pressing for solution—how to get the current from the dynamo to the lamp and how to supply commercially a number of lamps from one dynamo in such a way that some of them could be turned off without affecting others.

Several lamps were at first connected in series and operated by current of constant strength, as are street arc lamps today. The method of multiple connection was then proposed, requiring constant potential mains—the system by which over 99 percent of the electric power now generated is distributed. Nothing shows more clearly how far from present practice were the electrical ideas of a generation ago than the following quotation from a lecture in 1878 by one of the most eminent electrical engineers in England. After describing certain experiments in which the candle-power of lamps connected in multiple decreased very greatly as each lamp was added, he said, "Hence, a subdivision of light is an absolute ignis fatuus."

To maintain constant potential requires dynamos which produce constant potential and circuits causing small loss. Lamps of five or ten volts can be operated only a few feet from the source of power without large line loss unless the conductors be very heavy; the Edison lamp for 100 volts increased the practical distance to five hundred or a thousand feet. This was increased by the three-wire system and the feeder-main system. But the permissible cost of conductors was reached well within a mile. Four-wire and five-wire systems and various series systems which would enable 100 volt lamps to be served by circuits carrying 300 or 400 volts or more were found to be unsafe or unsuccessful. Electrical distribution seemed limited to a mile or less, except by the series system. A large part of the early edition of Kapp's "Electrical Transmission of Energy" is devoted to the characteristics of constant current series motors, the only method in view by which the high pressures necessary for long distances could be secured. The central stations for incandescent lighting, therefore, seemed doomed to mere spot lighting—the maps of a large city would show spots a mile or so in diameter each with its own central station.

About 1885 the attention of Mr. George Westinghouse, was called to the alternating-current transformer as an instrument by which current transmitted at high voltage could then be transformed to low voltage for the operation of incandescent lamps. He sent an investigator to England and then acquired the Gaulard and Gibbs patents. These involved induction coils or "inductoriums," which were open magnetic circuit transformers.

They were connected with their primary windings in series, while their secondary windings had the same number of turns as the primary and supplied independent circuits. The system employed constant current, and the lamps on the secondary circuits were subject to serious changes in voltage when the number of lamps on a transformer secondary circuit was varied.

Mr. William Stanley, who was then engaged principally in the development of the incandescent lamp for Mr. Westinghouse in Pittsburgh, had been much interested in the alternating current. A contract arrangement was made by which Mr. Stanley should undertake the development and adoption of the alternating system for commercial service. In the fall of 1885 he set to work in an old rubber mill at his home in Great Barrington, Mass., and constructed a number of transformers, each wound to reduce the 500 volt main line potential to 100 volts in their secondary circuits. These transformers differed from the Gaulard "inductoriums" in having the primary wound for a relatively high potential and in having the primary terminals connected in parallel to a constant potential circuit. The coils were made with a closed magnetic circuit and the general proportions of the transformers were remarkably similar to those of the modern "shell type." The idea of connecting a primary coil having a resistance of only one ohm between the mains of a 500 volt circuit was so palpable a violation of Ohm's Law as to shock the convictions and the experience of those who were familiar only with direct-current phenomena. It was a bold idea of a daring inventor who first did that with which all are now so familiar. Regardless of popular ideas, however, the transformers gave good promise and a Siemens machine which had been imported from England for tests at Pittsburgh was employed as a generator. The transformers were erected in the spring of 1886 and properly connected, and supplied a number of stores in Great Barrington with current on a commercial basis. The plant continued in operation for several months until a screw driver was accidentally dropped into the dynamo and wrecked the coils. The success of the initial plant led to the commercial adoption of the alternating-current system by the Westinghouse Electric Company. The misgivings of experts, the apprehensions of the dangers of high voltage, the antagonism of opposing commercial interests did not prevail and the little "twenty-five light" transformers opened the way for a new era in electric development.

After the wrecking of the Siemens machine, a new alternator, originating in plans made by Mr. Stanley, and worked out in detail designs by Mr. Shallenberger and Mr. Schmid, was built in Pittsburgh. A full equipment of commercial apparatus was quickly designed and manufactured, and soon alternating-current central stations appeared, first at Greensburg, then at Buffalo and elsewhere. Two years after the starting of the Great Barrington plant there were about a hundred alternating-current installations.

THE ALTERNATING CURRENT IN 1888

Having been asked to write the first of a series of historical articles on "The Engineering Evolution of Electrical Apparatus," it is but natural for me to go back to my own early experiences as a starting point. I have already given a preliminary survey of the electrical situation, and I shall now make a sort of an inventory of the kinds of apparatus which were being made when I took up electrical work in Pittsburgh about twenty-five years ago, and shall comment upon various points.

In the early part of August, 1888, I went to Pittsburgh and happily found that a personal application was more effective than correspondence in securing a position with the Westinghouse Electric Company. I had a slight acquaintance with Mr. L. B. Stillwell, then assistant electrician, as I had met him nearly a year before when he came to the Baldwin Locomotive Works where an alternating-current lighting plant was being installed and where I was then employed as wireman. Mr. Stillwell showed me about the laboratory in Pittsburgh, pointing out particularly two new kinds of apparatus which had recently been invented. One of these was the Shallenberger meter, an induction meter for registering the current used by the consumers on alternating-current circuits. At that time the chemical meter was generally used on direct-current circuits, and there was no commercial alternating-current house meter. The Shallenberger meter (which was already in substantially the same form which it maintained for a dozen years, during which time enormous numbers of meters were made) was the outcome of the observation of the peculiar motion of a spring lying upon an alternating-current arc lamp about four months earlier. Mr. O. B. Shallenberger, who was working with the lamp, investigated the motion of the little spring. He substituted other things in place of the spring and determined that the motion was due to the joint action of the magnetic fields set up by two circuits, in one of which the current lagged slightly in time behind the current in the other. Close observation, careful analysis, intelligent experiment, remarkable ability in designing and proportioning the new apparatus, which was to embody in commercial and useful form the principle exhibited by the moving spring, resulted in a few months in a meter which was the forerunner of the many types of induction meters which are now in general use.

The other new invention was the Tesla motor. Nikola Tesla had secured his patents and had presented a paper before the American Institute of Electrical Engineers, in the preceding May, describing the

rotating magnetic field produced by polyphase currents and the means of employing this in induction motors. The patents had been acquired by the Westinhouse Company and Mr. Tesla was then employed in the development of the apparatus into commercial form. The previous year had been fertile in the study of alternating-current phenomena. Patent litigation has since shown that the development of motion by currents differing in phase was shared by Tesla and Ferraris and Shallenberger and Stanley, and the priority of Tesla to the motor and Shallenberger to the meter were matters involving differences of only a few months, or even less.

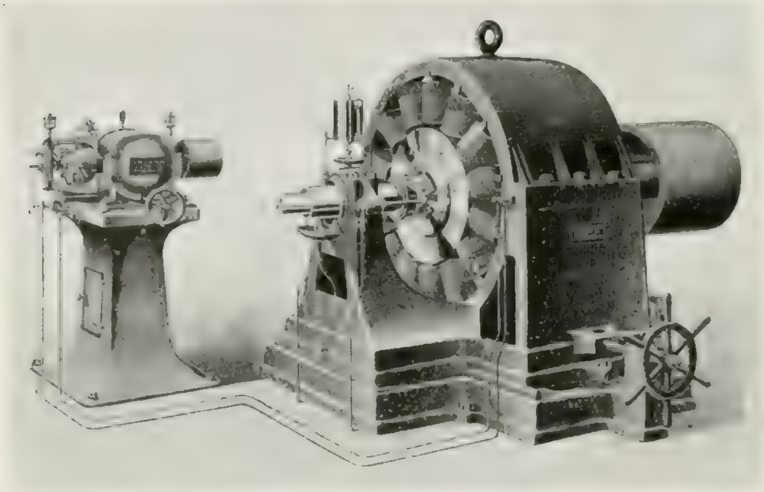


FIG. 1—1 500 LIGHT ALTERNATING-CURRENT DYNAMO WITH EXCITER—1888

EARLY ALTERNATORS

In the summer of 1888 the Westinghouse Company was making three sizes of alternators. To these a fourth and smaller size was soon added. These machines were belt driven and operated nominally at 1 000 volts and 16 000 alternations per minute, corresponding to 133 cycles per second. Further particulars are as follows:—

No. 0— 400 lights, 8 poles, 2 000 r. p. m.
No. 1— 700 lights, 10 poles, 1 600 r. p. m.
No. 2—1 350 lights, 14 poles, 1 150 r. p. m.
No. 3—2 500 lights, 16 poles, 1 050 r. p. m.

The machines were driven by high-speed belts, in many cases from Westinghouse automatic engines. The noise and whir of the great belts in stations where there were a number of generators inspired a kind of awe in the visitor, which is entirely lacking in the modern beltless power house. These alternating-current dynamos had cast iron field magnets and rotating drum armatures, as shown in the accompanying illustrations. The construction was simple in general and in detail. It was simple electrically, as compared with the direct-current dynamo with its intricate armature winding and commutator. An argument then presented was that brushes for collecting the current for a 1 500 light alternating-current dynamo have a width of 7/8 inch, whereas, the brushes for a 1 500 light dynamo of the direct-current type would have an aggregate width of 20 inches. This ratio is fairly illustrative of the relative requirements of the two systems in all their transmitting parts. The direct-current brushes of that day were of copper and were vastly more delicate and liable to injury by sparking and flashing than the carbon brushes which are now used. The alternators were simple mechanically. To appreciate this fact one has to go back to some treatise on dynamos published twenty years ago and observe the multitude of forms of machines. Each system and each inventor seemed to require a peculiar form. Now there are few types, many parts are common to machines of different kinds and the name plate instead of the form of the machine must be consulted to discover the maker. But nowhere is found the general simplicity and rigidity and the grace of form of this early alternator of Albert Schmid. The little exciter near the alternator in Fig. 1 looks peculiar while the alternator does not. The first was of an ephemeral type, while the latter is the prototype of many machines of today. It is a wise man who can devise the types which will continue. The bearings were supported directly by parts of the great casting which formed the base; they were large and amply lubricated

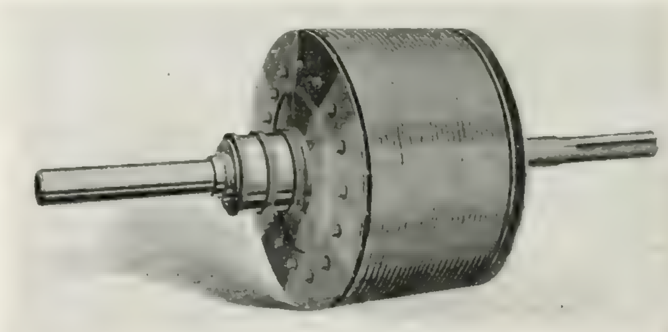


FIG. 2—ARMATURE OF ALTERNATING CURRENT DYNAMO

"An alternating-current armature is a structure of great directness and simplicity. The body of the armature is of laminated iron plates freely perforated for ventilating purposes. A single layer of wire is wound in flat coils back and forth across the face of the armature in a direction parallel to the shaft, being retained by stops on the ends of the armature. Mica and other adequate insulation is provided and the whole is wrapped with binding wire. A ventilator is attached to each end of the armature and draws a strong current of air through it. The total weight of copper on a 750-light armature is 16 lbs., disposed in a single layer, which being on the surface is readily kept cool, and can be inspected for deterioration or flaws of any character. A direct-current armature of the type most generally in use, of 750 lights capacity on the other hand, carries more than 10 times this amount of wire.

"We would call particular attention to the absence of a commutator, the place of which is supplied by two plain collecting rings without breaks of any kind. Narrow collectors rest upon these rings and serve to take off the current as it is generated. No practical operator of an electric light plant need be told of the annoyance due to the maintenance of a commutator, the brushes of which require exact adjustment, any departure being followed by destructive sparking."—1889.

by the dripping of oil from large brass reservoirs. Excellent as this may be, if testimony be needed as to the superiority of self-oiling bearings over the kind which needed fairly constant inspection to see that the oil dripped properly, which had to be filled frequently

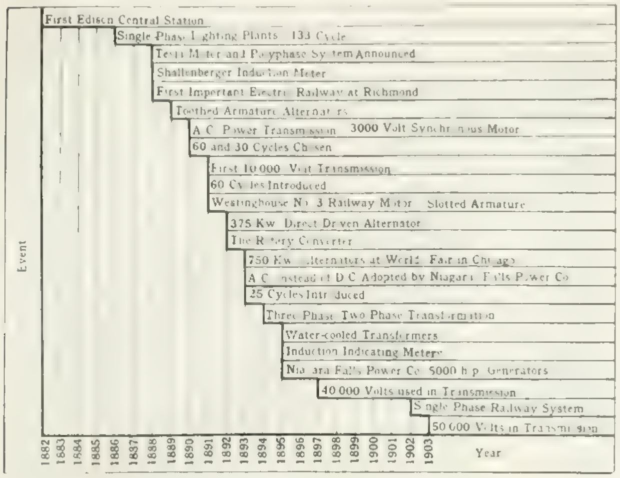


FIG. 3—CHRONOLOGICAL CHART OF SOME IMPORTANT EVENTS IN ELECTRICAL ENGINEERING HISTORY

and polished every night, the writer is prepared to testify from personal experience.

What were some of the limitations of the alternator which produced the current in hundreds of central stations for many years? It was heavy and expensive. Between the cylindrical surface of the iron core of the armature and the faces of the field poles must be space for insulation, for conductors, for insulation again and for band wires as well as free space between the band wires and the pole faces. Mechanically the space should be large; magnetically it should be small. If the armature got slightly out of center, it would strike the field poles, the band wires would give way and the "blowing up" of an armature was an exciting event. The life of the armature depended upon the integrity of a goodly fraction of a mile of steel band wire, wound under tension and subject to unknown stresses. The copper conductors could not be wound conveniently in more than a single layer, and the large conductors necessary for heavy currents in large alternators were heated by eddy currents generated in their motion through the magnetic field between the pole faces and the armature core. The band wires, being grouped together into bands in which the adjacent wires were soldered togther had heat producing currents induced in them in the same manner. Magnetic fields are apt to cause trouble when outside of their native element—iron. Winding in slots in modern armatures has replaced the old surface winding. Wires lying on a smooth cylindrical surface in a magnetic field have a "side force" on short-circuit which is hard to resist by any practical form of anchoring. Hence, a short-circuit used to cause mechanical damage followed by internal electrical distress and a season in the repair shop. In those days the skilled armature winder was the autocrat of the electrical industry. The slotted armature and the machine wound coil marked his doom.

The armature which immediately succeeded the first form was the toothed armature, which had a large tooth corresponding to each field pole, around which the armature coils were placed. The teeth had small projections at the circumference which served as a mechanical support for the coils. An armature of this kind was made for the field of the smallest alternator and was turned over to the writer to test. The air-gap was very small and the wire was large compared with that for the old drum armature; hence, a large output was anticipated. After obtaining the proper voltage and applying the load, the field current was increased as more and more lamps were added until presently there were a thousand lamps on what had been a 400 light machine. It was noted that the field current with the large load was three times what it had been with no load. The question came as to what would happen if all but a few lights were suddenly removed; would the voltage go to three times normal? This brought an appreciation for the first time of the significance of inherent regulation. Subsequently, the air-gap was made much larger and the regulation was very much improved. After a time the slotted armature con-

FIG. 4—THE CONVERTER OR TRANSFORMER

"It is a device of the simplest possible construction, having no moving parts whatever, its functions being purely electrical. It consists essentially of two coils, one of a given length of fine wire, called the 'primary coil' and receiving the current from the dynamo, the other of a short length of large wire, in which is induced the secondary current for lamp service."

struction, first finding favor in railway motors, was incorporated into generators and motors of all kinds.

TRANSFORMERS

The transformers (then called converters) which were made by the Westinghouse Company in

1888 were of five sizes, viz., of 5, 10, 20, 30 and 40 lamps the largest size being two kilowatts though the term kilowatts was not applied to them for several years. The transformers were wound for a primary e.m.f. of 1 000 volts and 50 volts secondary in most cases while a few were wound for 100 volts, usually with a tap at the middle point. The coils were separately wound and taped; they were approximately square in cross-section, so that the open-

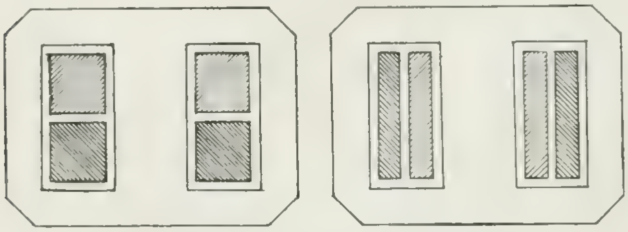


FIG. 5—FORMS OF COILS IN EARLY TRANSFORMERS

In parallel form the magnetic leakage between coils is considerable as there is a short wide path compared with that in the later concentric form, which therefore had much improved regulation.

ing in the iron was approximately a double square. The accompanying illustration shows such a transformer built up. Bare lead fuses, either wire or links, were placed between brass terminals on fibre bases in iron boxes on the case. Materials and construction of this sort would be wholly inadmissable today, though they were fairly satisfactory with the lesser currents, the lower e.m.f.s and the smaller generators which were then employed.

One of the difficulties with these transformers was the large drop in secondary voltage between no load and full load. This drop was partly caused by the resistance of the windings and partly by something else which was termed "drop due to iron." The latter was hard to measure accurately, as it seemed to vary from time to time. This factor was of serious importance when incandescent lamps constituted the only load, and it rose to very disagreeable proportions when there was a lagging current or, in modern terms, when the power-factor was low. The fact that the square coils were placed side by side in parallel form permitted a considerable magnetic leakage between the coils, the effect of which was very pronounced with the frequency of 133 cycles. The first modification in the transformer was to change the form of the coils, making them concentric by winding each coil with approximately twice the number of turns per layer and half the number of layers. This changed the path for the magnetic leakage, making it about twice as long and of one-half the cross-section that it was in the former arrangement, thereby improving the regulation.

The testing of transformers consisted of an insulation or a ground test and a running test. If the insulation was sufficient to prevent enough current from flowing through the primary of another transformer to light a lamp on its secondary, it was considered adequate. In other words, the insulation test was really made at an e.m.f. of 1 000 volts or less. The running test was made by coupling transformers in parallel to a large bank of lamps and running them for several hours.

AUXILIARY APPARATUS

While the generator and the transformer were the essential apparatus in the alternating system, various auxiliaries were necessary to make the system operative, such as switches, fuses, measuring instruments and the like. Past experience was limited to low voltage, direct-current service and to arc light circuits. Auxiliaries for alternating current and for 1 000 volt use had to be devised quickly. In the light of present knowledge they were simple and almost rudimentary. On the other hand, when one considers the limited experience there was to guide and the necessity for producing these instruments quickly, one cannot but admire the results. To Mr. Shallenberger and to Mr. Philip Lange, who was in charge of the construction of detail apparatus, belongs this credit in large measure. A number of points relating to this detail apparatus are of interest.

The rheostats had wooden face plates back of which were mounted wooden frames holding spirals of German silver wire.

The switches for the switchboards employed wooden bases and the contacts were open and exposed. Double-pole, double-throw switches were ordinarily employed for connecting a dynamo or an outgoing feeder to either of two sets of bus-bars. The transfer was made by throwing the switch quickly, resulting in only a momentary interruption of the circuit.

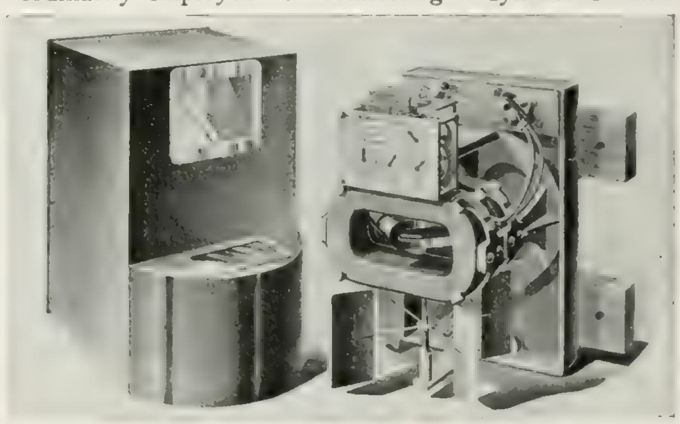


FIG. 6—FIRST SHALLENBERGER ALTERNATING-CURRENT METER

"The current passes through the main coils, creating a field through the coils at right angles to the back of the meter. Within the main coils is a secondary made of copper punchings which is placed at an angle of about 45 degrees with the main coils, thereby creating a magnetic field displaced by 45 degrees from that of the main coils. The secondary current and its magnetic field lag behind those of the main coils. In the space occupied by both fields is a thin aluminum disc supporting a small iron ring. This ring and disc revolve. The motion is retarded by fan blades at the bottom of the meter. The torque is proportional to the square of the current and the speed is proportional to the current, and the number of revolutions is registered on the dials."

The bus-bars for 1 000 volts were usually bare copper rods held by wooden supports on the front of the board. On one occasion a young electrician whose experience had been with batteries, joined the bars by a wire to see if he could get a spark. He did, but fortunately was not seriously burned. The safety catch or fuse was a wooden block about four inches square on which were mounted two lead fuses, one or both of which could be used, depending on the arrangement of the plugs which completed the circuit. The switchboard transformers were placed in wooden boxes and were mounted at the top of the board. The board on which the apparatus was mounted was either of matched flooring or was an open wood framework.

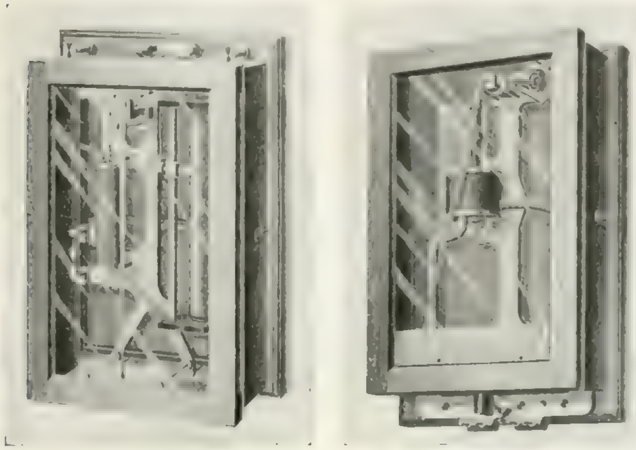


FIG. 7—STATION VOLTMETER AND AMMETER

"A solenoid pulls a soft iron wire plunger which is attached to one end of a lever which carries a weight at its other end. The e.m.f. necessary for causing the voltmeter pointer to come to the arrow is determined by the setting on the fixed resistance in the right hand side of the case."

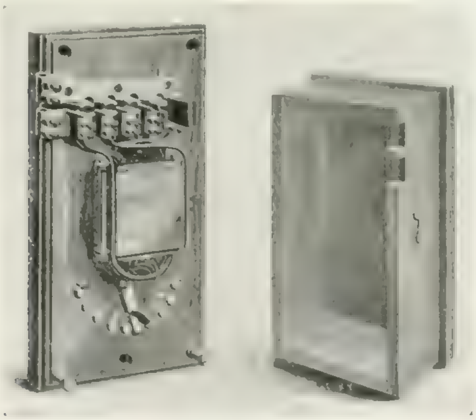


FIG. 8—VOLTMETER COMPENSATOR

"The number of turns through which the primary current passes is determined by the position of the plug near the top. The number of turns in the secondary winding which is in series with the voltmeter is adjusted by the switch near the bottom. In this manner the instrument can be adjusted to reduce the voltmeter reading by the same percentage as the line drop reduces the pressure at the lamps."

The early voltmeter had a lever on one end of which was a weight (adjustable by the number of shot in a brass cylinder), and on the other an iron wire plunger which extended into a solenoid. Incandescent lamps were used as a resistance in series with the solenoid. When the applied e.m.f. was at normal value, the pull by the solenoid was just sufficient to cause the pointer attached to the lever to point vertically. There was no graduation on the scale. This voltmeter was soon superseded by another in which German silver resistance replaced the lamps.

The ammeter needle traversed a circular dial under the action of a plunger in a solenoid which carried the main current. In a later form the mechanism was simpler, the deflection being indicated on a scale near the bottom of the instrument.

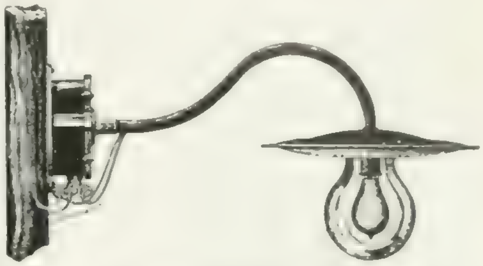


FIG. 9—STREET LAMP COIL, 1888

"These coils are so wound that twenty of them are placed in series when 1 000 volts are used. A 50 volt incandescent lamp is connected in shunt across each coil. When the lamp is burning the coil is 'not in action'; when it is broken the total current passes through the coil, which practically replaces the lamp. The brilliancy of the remaining lamps is not appreciably affected until five or six lamps are broken and then it is dimmed. This result is accomplished without any of the magnets or fusible connections or any of the moving parts or contacts which are annoying and crude accompaniments of many so-called series systems."

On the feeders were voltmeter compensators. These were series transformers, the primary circuit being in series with the feeder, and the secondary in series with the voltmeter. Outgoing current caused the voltmeter to read low, and it was necessary to raise the bus-bar e.m.f. in order that the voltmeter might give normal indication. The compensator caused a drop in the voltmeter circuit proportional to that in the feeder, so that when the voltmeter reading

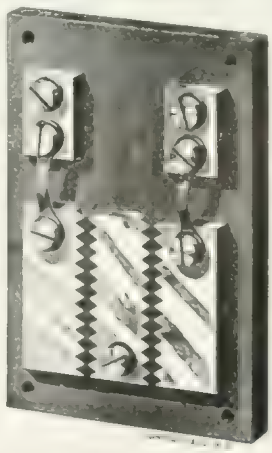


FIG. 10—LIGHTNING ARRESTER, 1888

This arrester was installed on 1 000 volt circuits. The middle section was grounded and the other two were connected to the dynamo terminals. It worked well if there was no lightning; but a spark was apt to be followed by dynamo current which volatilized the spark points and short-circuited the dynamo.

was normal the e.m.f. at the end of the feeder was normal also. When several feeders ran from the same bus-bars it was impossible to get the proper voltage for each one when the line losses were different, but a mean value could be selected. Recognizing this limitation, Mr. Stillwell devised, in the fall of 1888, the regulator which bore his name. A transformer had its primary coil connected between the two wires of the outgoing circuit and its secondary coil in series with the circuit, thereby increasing (or decreasing) the e.m.f. delivered to the circuit by the

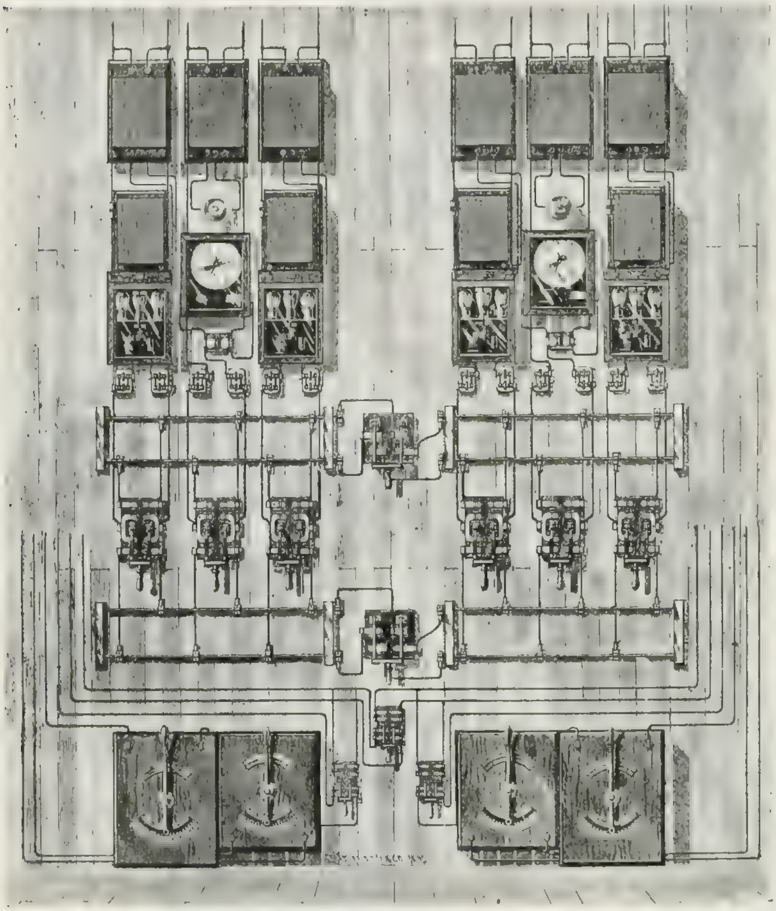


FIG. 11 — TYPICAL SWITCHBOARD OF 1888

"This switchboard accommodates two exciters, two 1 000 volt alternators and four feeders. The exciter control circuits are at the bottom of the board. The alternators are connected to the middle point of the middle switches of the right hand and left hand side of the board, and may be connected to the upper or the lower pairs of bus-bars. The right hand and left hand sections of each pair of bus-bars may be separate or connected in parallel by multiple arcing switches. The generator circuit is provided with a transformer, supplying a pilot lamp, and an ammeter with short circuiting plugs and fuse. Each feeder may be connected to the upper or lower bus-bars by a double throw switch and is provided with fuses, a voltmeter, a compensator and a transformer. Wood is the only insulating material used, except in the internal parts of transformers and instruments."

amount of the secondary e.m.f. The latter was adjustable by a change in the number of turns; hence the e.m.f. on an individual feeder could be adjusted to such a value that when reduced by the line drop the desired e.m.f. would be delivered to the load.

The early lightning arrester was a number of spark gaps in parallel between brass plates on a rubber base. This form was useful for the protection of telegraph circuits, but was utterly inadequate when current from a dynamo was ready to follow a spark. The researches and notable inventions of Wurts were the early chapters in the story of modern lightning protection. He began his work on the improvement of fuses and lightning arresters about 1888.

The change which has come about in measuring instruments is best indicated by a question which was recently asked by a young man who had spent a year or more in a large commercial testing room. He saw a Siemens electro-dynamometer in a college laboratory and inquired whether they were put to any practical use. He was told that in early testing room and laboratory work the dynamometer was the only instrument for measuring current with the exception of station instruments and a few small imported direct-current ammeters of doubtful quality. Even after the Weston direct-current ammeters came into general use in the early nineties, it was some time before there was a substitute for the dynamometer for the measurement of alternating current. During this early period practically the only voltmeter was the Cardew voltmeter, a hot wire instrument in which the fine wire was protected by a brass tube three or four feet long, the expansion of the wire being indicated by a pointer on a circular dial. This voltmeter was made for 60 volts and 120 volts, the former requiring about one-third of an ampere and the latter a somewhat less current at full deflection. For alternating-current power measurements, a dynamometer was used in which the series current passed through one coil and the shunt current passed through the other coil and a suitable non-inductive resistance. These were the best measuring appliances available. Sometimes the brilliancy of an incandescent lamp was used for indicating voltage, and Mr. Telsa insisted that he could determine the number of amperes taken by a fan motor by breaking the circuit and noting the size of the arc.

TESLA MOTORS

The first Tesla motors were made with definite iron field poles, similar in general form to a multipolar direct-current machine of the present day. The magnetic circuits were laminated; coils were placed around the individual poles. In a two-phase motor, alternate poles were connected as one circuit and the remaining poles as the second circuit. In each circuit

the coils were first positive and then negative. When current was passed through one circuit alone, alternate coils were energized, producing positive and negative poles. When the current through the first circuit decreased and that in the second increased, there was produced a succession of positive and negative poles, shifting from the angular position of the first circuit to that of the second. This shifting magnetic field acted upon an internal secondary member or armature. In the early motors this consisted of a smooth cylindrical core with wires wound in coils on

FIG. 12—SAFETY CATCH HOLDER OF SWITCHBOARD FUSE BLOCK

"This is used on 1 000 volt circuits. If the upper plug be removed, the right hand fuse alone is in circuit. If this fuse melts due to excessive current, a plug may be inserted in the upper position, thereby immediately placing the left hand fuse in service." In case of short-circuit, however, the whole block was apt to be enveloped in an arc which destroyed the metal terminals, as well as the wood base.

the surface, these coils being short-circuited. There were usually as many windings as there were total field poles in the two primary circuits. Motors of this type would usually start fairly well and were able to carry a fair load. They took, however, a large magnetizing current due to the limited pole surface and to the relatively large air-gap between the iron of the stationary poles and the iron surface of the rotating core.

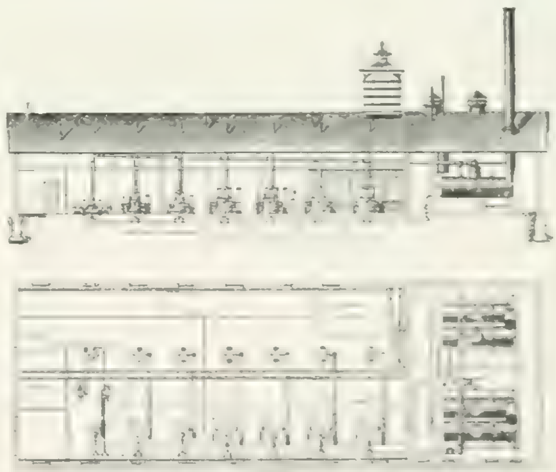
Furthermore, as the magnetic fields from the two primary circuits enter the secondary at definite independent positions, a coil on the rotating member in certain positions would confront one field pole only and in other positions might confront one field pole of each circuit and receive induction from both. Hence there was lack of uniformity of action and dead points sometimes resulted. Furthermore, if the rotating member were made with definite poles, so that the air-gap might be reduced, the excellence of the magnetic circuit varied for different angular positions of the secondary. These difficulties were in large measure overcome by making the secondary core with a large number of small slots and small teeth. In the slots were placed the coils with windings so distributed that the resultant action in the secondary was practically the same, whatever the angular position of the secondary. Later on the primary was also provided with a large number of small slots in which the windings were so distributed that several primary circuits produced a practically uniform rotating magnetic field. In such a field the secondary winding does not need to be specially distributed and the squirrel cage type can be employed in which each conductor is connected to a ring at each end of the secondary.

The method of winding in small slots, instead of placing the windings on the surface of an armature or around large poles made a radical change in the design of alternators, induction motors and direct-current generators. The first important machine of this type which was made in Pittsburgh was the No. 3 railway motor which combined a large number of characteristic features, making it the prototype of the modern railway motor. This new type of winding apparently sacrificed some of the best features of the induction motor. The simplicity of the early machine was unique. The primary windings were in a few coils as simple as ordinary field coils, readily wound, easily put in place and replaced. To separate this winding into many small coils to be placed in small slots was unfortunate from the standpoint of simplicity and insulation.

The early endeavor was to adapt the induction motor to 133 cycles and by "split phase" or other methods to operate it on the existing single-phase circuits. It is no wonder that little headway was made in solving a problem which scarcely any one would attempt today. The motor could not be adapted to the frequency, and so the frequency was adapted to the motor.

FREQUENCY

The frequency of the early apparatus was 133 cycles, or 16 000 alternations per minute as it was then ordinarily designated. About the time the writer



[illegible]

The station at East Liberty typifies the early alternating station. A turbo-generator having ten times the output of the whole station would not take the floor space occupied by one of the six belted units.

went to Pittsburgh, tests were being carried on to determine the performance of transformers at lower frequencies. As adequate measuring instruments were not available, the method of test was to use a large ice calorimeter. The transformer was placed in the calorimeter for a number of hours and the weight of the melted ice was taken to indicate the loss in the transformer. Two of the important reasons making a lower frequency desirable were the generator and the Tesla motor. It was seen that in order to avoid

belts, it would be necessary to run alternators at a low speed for direct connection to engines. This made desirable a less number of poles than would be necessary for the high frequency, for instance, at 100 r.p.m. 160 poles would be necessary. Furthermore, the induction motor operated much more satisfactorily at a low frequency.

In the fall of 1890 Mr. Stillwell returned from a visit to Europe. He had seen alternators direct connected to slow-speed engines. After carefully studying the American situation he prepared a report on which the subsequent engineering policy of the company was based, in which a frequency of 60 cycles was proposed as a general standard for lighting service and 30 cycles for power service. The higher frequency met the requirements of engine speed; it permitted transformers to be made at reasonable cost (the cost increased as the frequency was lowered) and it was high enough to permit the operation of arc lamps without flicker, with American carbons. Abroad

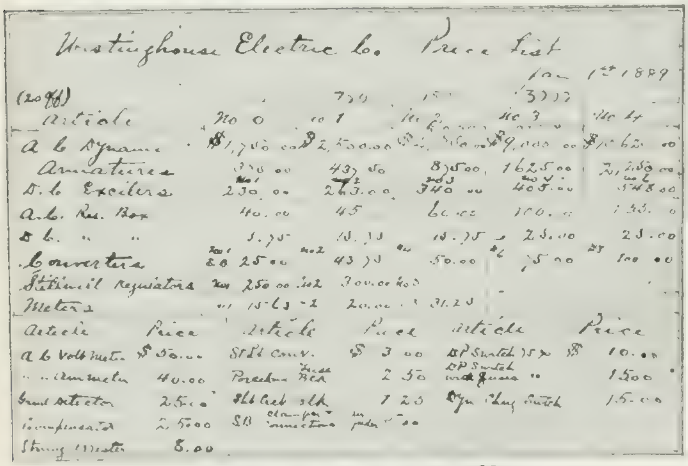


FIG. 14—PRICE LIST, 1889

This list, torn from an ordinary note-book, included prices, not only on all types of apparatus manufactured by the company, but on all the ratings of each type.

soft carbons permitted a slightly lower frequency. The lower frequency of 30 cycles seem a desirable one from the standpoint of the induction motor and power work generally. In 1892 an exhibition of alternating apparatus was made at Pittsburgh which was viewed by Prof. George Forbes of England, Prof. Henry A. Rowland and Dr. Coleman Sellers members of the commission for determining the system to be adopted by the Niagara Falls Power Company. They were shown rotary converters operating at 30 cycles. The matter of frequency was discussed. The effect on incandescent lamps was determined to be unobservable at 30 cycles, very pronounced at 20 cycles and somewhat in question at 25. Prof. Rowland remarked that the way to make a test was to have some old woman read by the light and note whether or not her eyes became tired. This seemed a remarkable statement from the leading physicist of America with regard to what seemed to be a physical phenomenon, but after all it is not physical condition but physiological effect that is of importance. The commission of American and foreign engineers which determined the system to be used at Niagara was at first in favor of direct current by a considerable majority. The final decision in favor of alternating current was not made until the summer of 1893 when polyphase alternating current was choosen and a little later 25 cycle alternators of 5 000 horse-power, delivering two phase current were purchased from the Westinghouse Company. The design of the alternators favored either a 12 pole or a 16 pole alternator. The water turbines had been purchased; they ran at 250 r.p.m. Hence the choice lay between 25 and 33 1/3 cycles and it was impossible to secure 30 cycles. The 12 pole machine giving 25 cycles was chosen. This was a notable event. The adoption of polyphase alternating current and the use of 25 cycles by the largest power undertaking of the time set a precedent which is now almost universally followed. Frequencies of 40 and 50 and 66 cycles have been advocated and used, but (with few exceptions) are now obsolete.

THE IMPORTANCE OF TRANSFORMER AND POLYPHASE SYSTEM

In the early days, say from 1880 to 1895, there were many systems and many types of apparatus. This is well illustrated by one station which had machines for arc lighting at 6.6 amperes, for arc lighting at 10 amperes, for incandescent lighting by the three-wire system, for power by 500 volts direct current, and for incandescent lighting by alternating current. Each kind of service required its own individual circuits and the arc lighting required individual circuits from each machine. Subsequently current for all kinds of service was derived from alternators far greater in capacity than a score of the former machines.

If we were to trace the electric development of the past twenty-five years, we should find the transformer as the simple factor which has determined the whole course of that development. With few exceptions in which direct current from relatively small plants is used locally, practically all of the electric energy now used for lighting and for power purposes passes through one or more transformers.

A second factor in shaping the course of electrical development was the Tesla motor and the polyphase system. To accommodate the motor with a proper supply of current, single-phase generators gave way to polyphase alternators, and high frequency was followed by low. The Tesla invention proved to be not merely a motor, as was first assumed, but a system. Polyphase apparatus is now practically universal. All of the long distance systems of power transmission and practically all of the great central stations for street railway and lighting and power service produce polyphase alternating current, even when the consumption circuits require direct current. When the polyphase system was first introduced, the parallel operation of alternators was unusual, but it is now universal.

Without the transformer and the polyphase system there is no means at present known by which the extension of the use of electricity could have made one-tenth of the progress that it has made. It is easy to recognize this now, but it was not so easy to foresee. In fact, there was criticism and condemnation of the alternating current by experts, and there was antagonism and opposition by commercial interests. The foresight, the courage and the wonderful constructive ability, persistence and power of Mr. Westinghouse made him the great human factor in the recognition, introduction and development of the alternating system, and, therefore, in the electrical development of the past twenty-five years.

Those only who were associated with the company before the writer went to Pittsburgh have been mentioned. Among the first of those who followed and who have had a great deal to do with the subsequent development of apparatus, including some of the types to which reference has already been made, were Messrs, Lamme and Storer and Skinner and Davis. It is anticipated that further articles by various men will trace the engineering steps which have led up to the efficient apparatus of to-day. Present practice is the outcome of the efforts of many workers in many places. The particular thing which may bear the impress of a particular inventor or may be put forward with energy by one company or another may flourish for a time, but merit determines its final disposition. Among the types of apparatus which are now in common use and in many cases are manufactured by several companies it will be interesting to note that a considerable number had their origin Pittsburgh. In many cases the idea originated with a Pittsburgh inventor. In other cases an acute engineering instinct has selected, combined and put into operating form apparatus or methods which were previously undeveloped or experimental.

Some Applications of Electric Arc Welding

E. S. Zuck

ALTHOUGH the several processes of welding iron and steel by means of the electric arc have been known for years, their application to useful service in the various industries has been comparatively slow. This has probably been due to the fact that a thorough knowledge of the art has been in the hands of comparatively few men. There has also existed an impression that electric arc welding is expected to replace largely blacksmith welding. The electric process, on the contrary, has a distinct field of its own. As will be pointed out later, it is possible to do things with electric arc welding which the modern blacksmith could not accomplish by any means. In the few cases where the methods do overlap, it is largely on account of cheapness that the electric process excels.

There are two methods of electric arc welding now used to the practical exclusion of all others. These are briefly, the carbon electrode arc, known to many as the Benardos process, and the metallic electrode arc, known as the Slavianoff process. In the carbon process, as the name implies, a carbon electrode is used as one terminal of the electric circuit, while the article to be welded is made the opposite terminal, and the arc by which welding is accomplished is drawn between these two electrodes. For heavy cutting, for the repair of defective castings, and for general welding work this process is used. For lighter service, general repair work, etc., the metallic electrode process is used, differing only in that a metal electrode, usually an iron rod of small diameter, is used instead of the carbon.

The characteristics of the arcs in these two processes are somewhat different. The carbon arc for average work usually requires from 350 to 400 amperes, with a voltage drop across the arc of from 40 to 50 volts. The arc is also from three to four inches long. The arc of the metal electrode, on the contrary, is quite short; seldom being over 3/16 inch long, and usually less. The current required is approximately 150 amperes with a voltage across the arc of from 25 to 30 volts. Resistance is used in series with the arc in each type to steady the arc. It should be mentioned here that, although practically all metal electrode welding is done with current and voltage as mentioned above, carbon welding sometimes requires very heavy currents. In fact there are cases on record where, for some particular job, currents as high as 1 500 amperes have been used. This is, of course, exceptional and has no bearing on average practice.

Although current for welding can be taken from any direct-current system, providing sufficient resistance be used to reduce the voltage to that required at the arc, it is economy to use a low voltage generator driven either by a belted motor or direct-connected as a motor-generator set. This arrangement is necessary where only alternating current is available. Generators delivering 75 volts have been found to be quite satisfactory. The generator should be compound wound so that several arcs may be operated from it simultaneously, especially if metallic electrode arcs are used, as they are very sensitive to sudden changes in voltage. If only one arc is to be

operated, the generator should preferably be shunt wound, this type having a drooping voltage characteristic, which serves to protect the apparatus in case of short-circuit.

The application of the electric process of welding has been growing within recent years and it is rapidly becoming useful in many industries.* Steam

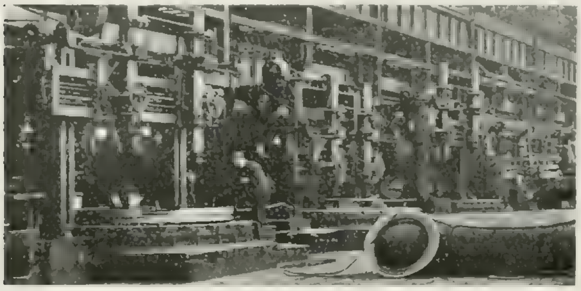


FIG. 1—FILLING UP BLOW-HOLES IN A PARTIALLY MACHINED CASTING, WITHOUT REMOVING THE WORK FROM THE MACHINE

railroads have been trying out the electric process for various kinds of work in their shops and have recently expressed themselves in favor of the electric process for several applications formerly supposed to be in the field of gas welding. After a year's investigation, a standing committee of steam railroad motive power engineers reported briefly as follows:—"The committee feels that there is a field in which each of the two welders, that is, the electric and the oxy-acetylene, excels the other. For welding seams, cutting out and removing old sheets, the oxy-acetylene excels. For welding flues and short cracks and welding metal where expansion must be taken care of, the electric welder excels."

Undoubtedly the welding of flues in locomotive boilers offers the best field for electric welding in steam railway shops. In order to show the advantages of welded flues, the method of placing flues in the front and rear sheets is described briefly. Referring to Fig. 2, (*a*) shows a tube set in position and

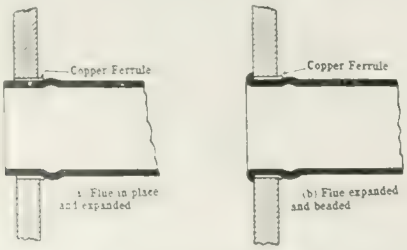


FIG. 2—OLD METHOD OF EXPANDING AND BEADING OVER BOILER FLUES IN END SHEETS WITHOUT WELDING

expanded and (*b*) shows the tube after the process of beading has been completed. It is evident that under the best conditions, there is a joint between tube and sheet which, in time, due to expansion, contraction and strain, will become loose and leak.

If, however, the flues can be welded in, it is evident that an enormous amount of trouble, due to leakage around flues, can be eliminated. A number of methods used in welding flues by the electric process are shown in Fig. 3. All of the sketches show the flue simply set into position in the sheet without the use of any copper ferrules and without beading and expanding. A comparatively deep and narrow counterbore is shown in Fig. 3 (*a*). It was found, after welding several samples counterbored in this manner, that the counterbore was not completely filled in with metal. This was particularly true at

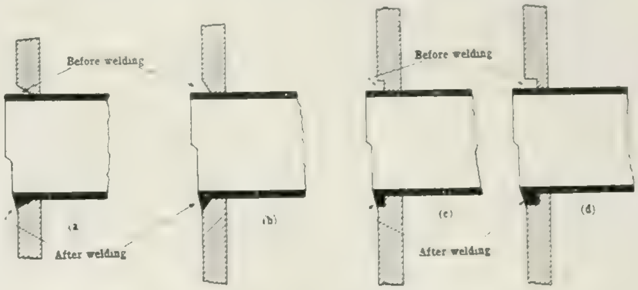


FIG. 3—VARIOUS METHODS USED IN WELDING BOILER FLUES IN PLACE

the bottom of the counterbore, a small space being left unfilled. By making the counterbore not so deep and wider, as shown at (*b*), the weld was found to fill the counterbore completely. In (*c*) a counterbore of different shape was used (the only difference between (*c*) and (*d*) being the depth of the counterbore), which was found to give, if anything, a better result. It should be mentioned here that in order to determine the relative results with the above methods, the tubes were cut off after weld-

FIG. 4—WELDING FLUES IN A LOCOMOTIVE BOILER

ing, flush with the sheet, and then the sheet cut through the weld in a number of places.

Flues are welded by the metallic electrode process, using about 150 amperes with approximately 30 volts drop across the arc. No difficulty is experienced in welding in a vertical plane with the ordinary iron wire electrode. The electrode material is generally iron wire, about one-eighth inch in diameter. A special low carbon steel wire has also

*See the JOURNAL for Jan., 1908, p. 18, and March, 1913, p. 199.

been found to give very good results. No flux is required, although it is important to keep the surface clean and free from dirt, scale and grease.

There will, of course, be occasional imperfect welds. These, however, are no more serious than leaking joints. The present indications are that if flues are welded in, they can be run for three years,

FIG. 5—WELDING BY BOTH METHODS; CARBON ELECTRODE AT THE LEFT AND METALLIC AT THE RIGHT

which is the limit prescribed by the Federal rules. A view of the process of welding flues in a locomotive boiler is given in Fig. 4.

The various seams and stay bolts in locomotive boilers are another source of constant trouble, leaks resulting from constant expansion and contraction of joints in service. These cases are well suited for welding by the electric arc.

The two types of welding are shown in Fig. 5, the workman on the left using the carbon electrode, and the one on the right the metallic electrode. The method of welding short cracks is clearly shown in

FIG. 6—WORN MUD RING FROM A LOCOMOTIVE BEING BUILT UP BY ELECTRIC WELDING

this figure. The crack is first "V'd" out, as shown at *A* to the extreme right. It is then filled in so that the finished weld is flush with the surface, as shown at *B*.

The electric process has a marked advantage over the gas flame in welding many classes of work. The gas flame does not bring the metal at once to a welding temperature, and thus allows the heat to spread more or less through the sheet or material to be welded. After the weld is made, the work cools, and, on account of contraction, strains are set up which tend to tear the weld apart, and often do. With the electric process, however, the heating is almost entirely localized, thus practically avoiding cooling strains after the weld is completed. There are some cases, however, where it is best to preheat the work before welding, in order to insure even and uniform contraction throughout when cooling. This applies to both the gas and electric processes.

Fig. 6 shows how worn mud rings can be built up by welding on new metal. For this class of work the electric process is particularly well adapted. There are a great many wearing parts on locomotives and cars which can be easily and cheaply made

FIG. 7—REPAIRING A CRACK IN THE FRAME OF A LOCOMOTIVE BY THE METALLIC ELECTRODE ARC

as good as new by this building-up process. Occasionally locomotive frames crack, as in Fig. 7. It is a comparatively simple operation to "V" out the crack, and then to weld. With proper care, a weld as strong as the original material can be made. Ordinarily, it would be necessary to dismantle the entire locomotive in order to repair a break of this character. Electric welding saves all such expense. There are several cases on record where locomotive frames have been welded by this means without even withdrawing the locomotive from service.

In street railway shops the electric process can be used in repairing broken motor frames, worn trucks, brake rigging and many other parts subject to wear. An interesting application is that of building up worn frogs and crossings. These can be renewed by welding on new metal and then grinding them to shape. A large saving can be effected, not only the expense of supplying a new frog or cross-

over being avoided, but also the expense of installation, which is often quite heavy on account of the serious interruption of traffic. The electric process need interfere but little with traffic. It is also possible to control to a certain degree the hardness of the weld, hardness being a good quality of frogs and crossings, which are subject in service to a continual succession of blows from the wheels of rolling stock.

In much the same manner that steam railroads are taking advantage of electric welding, steamship companies are also being benefited. Repairs on boilers are made quickly. In many of our large seaports there are concerns making a business of marine repair work. For instance, a steamship comes into port with leaky boilers. While the cargo is being unloaded, a small vessel, usually a tug boat, carrying the necessary generating and control equipment, is run alongside the ship; cables are carried into the boiler room through the port holes and the boilers repaired by electric welding. Broken stern frames, propellers, and damaged plates in the hull can be repaired quickly, although it is generally necessary to dry-dock the vessel for repairs of this nature.

In foundries and machine shops, broken steel castings and defective castings can be reclaimed, thereby effecting great savings. Occasionally, during the operation of machining a casting, a large blowhole will develop. Without removing the piece from the machine tool, the blow hole can be filled up, as shown in Fig. 1, and the work continued without the loss of more than 15 minutes time.

Another exceedingly satisfactory application of the electric arc is found in the operation of opening tap holes and tuyeres in furnaces. The furnace is made the positive terminal of the circuit, and the negative terminal is a solid carbon rod two inches in diameter and four feet long filled into one end of a wrought iron pipe, which, at the other end is provided with a wooden handle. The entire length is about ten feet.

OVERHEAD WELDING

Concerning the subject of overhead welding, there has been much discussion. Several schemes have been brought forward to accomplish overhead welding, each one being claimed by its originator to be the only successful method. One of these schemes involves the use of a special electrode holder, containing a coil usually in shunt with the arc. It is claimed that the coil sets up a magnetic field in such a direction as to direct the particles of molten metal from the electrode to the weld, thus causing the particles to attach themselves to the article being welded. If, however, it is remembered that at temperatures above approximately 750 degrees C. iron becomes non-magnetic, the error of this claim becomes self-evident.

Another method is the one making use of a metallic electrode coated with a non-combustible and non-conducting material, which has the effect of causing the end of the metal electrode to melt, in the shape of a cup thus holding the molten material in place while being distributed upon the weld. Following closely in the path of this argument, is that advanced by others which explains the possibility of welding overhead by the so-called "pinch effect." This "pinching" effect is caused by the magnetic field which surrounds any conductor carrying current, and which tends to contract the material of the conductor. Obviously, it has no effect on a solid conductor, but if the conductor be fluid or semi-fluid, it causes the material to contract, or pinch. That the pinch effect exists, there is no question. A good illustration is that of a column of mercury lying in a horizontal position. If sufficient current be passed through the column, the magnetic field set up about the column is of such strength as to cause the column to separate. How far this effect goes in successful overhead welding it is difficult to say. It is claimed that a coating around the electrode is necessary. This coating may be of considerable thickness, or it may be quite thin, as for instance a metal electrode simply covered with a suitable welding flux. The fact remains, however, that overhead welding is at best rather uncertain. Experience has shown that in the hands of skilled operators overhead welding can be done without flux coating on the electrode and without any special holder.

All of this only goes to show that success in electric arc welding is, after all, largely a matter of the skill and experience of the operator. The relations of current, voltage and length of arc are now sufficiently well known, so that failure to achieve success in the process can not be laid to these elements. It remains, therefore, for those wishing to benefit by the process to secure the skill and experience required in the successful practice of the art.

Purchased Power and the Leather Industry

A. E. Rickards

POWER companies are inclined to consider a tannery as a poor prospect for their service because of the large quantity of steam required in the process of manufacturing. They consider that all tanners have a large amount of spent tan which must be disposed of, and that this furnishes practically all the fuel necessary. As a matter of fact the steam used in manufacturing leather at the present time is for the most part live steam; furthermore, the quantity used has become proportionately less each year due to the increased use of patented tanning solutions. The use of these solutions, replacing the liquor formerly obtained from tan bark, has greatly decreased the supply of spent tan bark available for fuel. Hence, it has become necessary to use coal for the steam requirements.

The general situation before the leather manufacturers is as follows:—

1—The value of their products increased 52 percent in the past decade, and will probably increase about 35 percent in the next decade.
2—The primary horse-power increased 137 percent per establishment in the past decade and must continue to increase to meet the increased production.
3—The correct use of steam and the proper application of motors will increase the production in an average tannery 15 percent, which will in turn increase the profit at least 36 percent.

These statements must not be interpreted to mean that the central station can now get power contracts from tannery operators merely for the asking. The leather manufacturers are just as ignorant of the possibilities of purchased power as the power companies are of the tanning industry. In order that they may use central station power advantageously or, more clearly, in order that the cost of power plus the cost to make the steam for manufacturing be less than the total isolated plant costs, the tanners must know how to generate and use steam economically, and how to operate their productive machinery to secure the maximum output with a minimum power consumption. If these improvements are not provided for, the total costs with purchased power may not be less than the isolated plant costs, and as a result the power company will have a dissatisfied customer, who will not only terminate his contract when it expires, but will be a poor advertiser for future business.

The correct use of steam and power means not only a saving in operating costs, but usually results in obtaining a greater output. The correct arrangement of motors will allow the placing of the machinery so that the material can be handled at a minimum expense. The correct sizes of motors means a saving in the first cost as well as in the cost of operation.

The power required to operate the various machines is almost invariably over-estimated by tanners. The figures given in Table I were obtained from a tannery using extracts exclusively and having an output of 90 000 hides per year. Within the past three months a very large Eastern tannery, having a modern turbo-generator plant operated condensing, has seen fit to discontinue the use of their own power plant and are now using central station service. This company will save about $5 000 per year, about a third of the saving being expected from improved drainage of steam lines and better coal handling facilities.

The data here given, which is compiled from the United States census reports, shows the present conditions of the tannery industry and the probabilities for the future, and will be useful in opening up a negotiation with the manufacturer.

Before proceeding further it will be interesting to review briefly the history of the leather industry.

THE PAST

Making leather is one of the very oldest of industries; man made leather before he knew how to work metal. Previous to 1880, manufacturing leather was a combination of manual labor and chemistry. Any attempt to supersede manual labor with machinery was discouraged and old formulas were seemingly preferred. These formulas were handed down from father to son for generations. Very few would take advantage of the scientific knowledge the chemists had to offer in the way of improved and more economical methods.

As a result of these prejudices, the progress of the business, previous to 1880, was slight. However, from that time up to the present the tanners have adopted the most radical changes, so that today the industry is completely revolutionized. They have not only adopted many patented processes of tanning, but have also installed machinery which greatly reduces the labor. From 1880 to the present day the tanners have been no less enterprising in the use of modern methods and inventions than the leaders in any other line of manufacture.

THE PRESENT

The present situation before the leather manufacturers can be shown by analyzing the census reports. The first four tables in this paper show:—

1—The size and growth of the industry, as a whole.
2—The condition of and the amount of business done by the average establishment.
3—The details of the cost to manufacture $100 worth of leather.
4—The value of the output and its cost per $100 capital invested.

In Table I is shown the growth of the leather industry since 1900, and the number or value for all establishments. Inspection shows that the number of establishments decreased 29 percent in ten years. This does not indicate that competition became less.

TABLE I—CENSUS ANALYSIS OF THE LEATHER INDUSTRY

All Establishments

Item	1900	1910	Percent Change in 10 Years.
Number of establishments	1306	919	29.0—
Capital	$173 977 000	$323 597 000	86.0+
Primary horse power	88 860	146 140	66.5+
Number of salaried employees	2 442	4 114	68.4+
Number of wage earners	52 109	62 202	19.2
Value of products	$204 038 000	$327 874 000	60.0+
COST ITEMS			
Cost of materials	$155 000 000	$248 279 006	60.0+
Wages	22 591 000	32 103 600	42.0+
Salaries	3 159 000	6 755 000	113.0+
Miscellaneous expenses	7 024 000	12 414 000	76.0+
Total cost	187 774 000	299 551 000	59.4+
Gross profit	16 264 000	28 323 000	74.2+
Percent profit on capital	9.37	8.77	6.4—

The decrease was brought about through the formation of large corporations, which, after acquiring a number of tanneries, closed down the least profitable.

The capital increased 86 percent; also the primary horse-power increased 66.5 percent. The large increase in the primary horse-power was caused by extensive installations of machinery, to operate which required increased capacity in power plants. All these improvements must have required the expenditure of a considerable portion of the new capital.

Wages and salaries show a greater increase than the increase in the number of wage earners and salaried employes. This shows that the average individual is receiving more money than formerly. For instance, in 1900 the tannery hands earned an average wage of $433.24 per year; in 1910 they earned $516.10, an increase of 19 percent. Salaried employes received an average of $1 293.21 in 1900, and $1 641.95 in 1910, an increase of 27 percent.

Table II shows more clearly the condition of the average tannery. From this it will be noted that the

TABLE II—CENSUS ANALYSIS OF THE LEATHER INDUSTRY

Showing number or value per establishment

Item	1900	1910	Percent Change in 10 Years.
Capital	$133 198	$352 117	164. +
Value of product	156 231	356 772	129. +
COST ITEMS.			
Cost of materials	$118 701	$270 162	128. +
Wages	17 298	34 932	102. +
Salaries	2 418	7 350	204. +
Miscellaneous expenses	5 370	13 562	152. +
Total cost	143 787	326 006	127. +
Gross profit	12 444	30 766	147. +
Percent profit on capital	9.37	8.77	6.9—
Primary horse-power	68	161	137. +
Number of salaried employees	1.8	4.4	144. +
Number of wage earners	39	68	74. +

value of the products has increased 129 percent. The increase in production required more machinery; to drive the machinery it was necessary to increase the capacity of the power plants 137 percent. These improvements required additional capital. The first item shows that the capital increased 164 percent.

Table III shows the cost to manufacture $100 worth of leather. It is an analysis of Table I and is worked out upon the value or number for each $100 worth of goods produced. The bulk cost for the raw materials used in making leather has increased considerably. However, the second item shows that the cost of materials per $100 of product has decreased 0.32 percent. This indicates that the tanners are more economical in their manufacturing methods than formerly. The wages per unit decreased 13 percent and the number of wage earners 3.1 percent. These figures show that although the tanners are paying the

TABLE III—NUMBER OR VALUE FOR EACH $100 VALUE OF PRODUCT

Item.	1900	1910	Percent Change in 10 Years
Capital	$85.35	$98.73	15.6 +
COST ITEMS			
Materials	$75.96	$75.72	0.32—
Wages	11.07	9.79	13.0 —
Salaries	1.54	2.06	33.8 +
Miscellaneous	3.44	3.78	0.99+
Total cost	92.01	91.35	0.72—
Gross Profit	7.99	8.65	8.3 +
Percent profit on capital	9.37	8.77	6.9 —
Primary horse-power	0.043	0.042	2.3 —
Number of salaried employees.	0.0012	0.0013	8.0 +
Number of wage earners	0.025	0.019	3.1 —

individual laborers more money, they are getting more efficient results from them. This is because the laborer is more intelligent and also because of the greater use of machinery.

Table IV is compiled to determine what profit is made by the tanners. Again this is an analysis of Table I. It shows that the earning power of the capital became less. For instance, in 1900 there was $117.28 worth of leather produced for each $100 capital invested, while in 1910 there was only $101.32 produced per $100 invested. The percent profit upon

TABLE IV—NUMBER OR VALUE PER $100 CAPITAL

Item	1900	1910	Percent Change in 10 Years.
Capital	$173 977 000	$323 597 000	86.0 +
Value of product	117.28	101.32	15.7 —
COST ITEMS.			
Cost of materials	$ 89 08	$76.72	16.0 —
Wages	12.98	9.91	30.9 —
Salaries	1.81	2.09	15.4 +
Miscellaneous expenses	4.04	3.83	5.5 —
Total cost	107.91	92.55	16.5 —
Gross profit	9.37	8.77	6.85—
Percent profit on capital	9.37	8.77	6.85—
Primary horse-power	0.051	0.045	13.3
Number of salaried employees.	0.0014	0.0014	0
Number of wage earners	0.029	0.019	52.7 —

the capital decreased 6.85 percent. The census reports do not include depreciation or obsolescence upon the factory or the equipment, nor the interest upon preferred stock or loans. If these fixed charges were added to the cost of manufacture, the profits shown in these tables would, of course, be much less.

The price of hides and skins has increased because the domestic supply has not been sufficient to meet the demand. This situation has existed since 1815, and the quantity imported has increased each year. The value of importations in 1900 amounted to $19 400 000, while in 1910 it exceeded $50 000 000.

It is hardly probable that the price of leather will ever be much less than it is today. The upward

tendency of prices can readily be appreciated by referring to Figs 3, 4 and 5, which show graphically the average price per year from 1890 to 1911, for oak and hemlock sole leather and harness leather.

THE FUTURE

It is estimated that in the year 1920 there will be $460 000 000 worth of leather manufactured in the United States. This amount exceeds the production of 1910 by $133 000 000. This figure was obtained as follows:—

FIG. 1—TWO EIGHT BY SIX FOOT TANNING DRUMS DRIVEN BY A FIFTEEN HORSE-POWER MOTOR

There are two features that have a material bearing upon the demand for leather; these are, the increase in the population of the country and the increase in the consumption of leather per capita. People are continually finding many new uses for leather goods. The population of this country has increased at an average rate of 23.5 percent per decade for the past fifty years. On this basis the population in 1920 will be 113 475 000. The demand for leather has increased at an average rate of 13.5 percent per decade per capita for the past half century. The leather consumption per capita was $3.56 in 1910. An increase of 13.5 percent will bring this figure up to $4.05 in 1920. With a population of 113 475 000 in 1920, and a demand for leather of $4.05 per capita, the total value of the output will be $460 000 000, an increase of 40 percent over the quantity made in 1910. In Fig. 6 is illustrated graphically the value of tannery products from 1860 to 1910, the dotted line indicating the estimate for 1920.

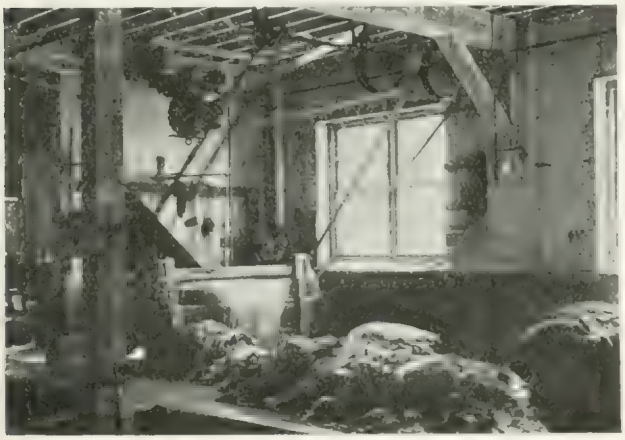


FIG. 2—FLESHING MACHINE DRIVEN BY A FIVE HORSE-POWER MOTOR

A comparison of the population and the value of tannery products is given in Table V, and is the basis of the foregoing estimate. A study of the figures contained in this table, together with Fig. 6, will indicate that the prediction for 1920 is consistent with the growth in the past.

THE PRESENT SITUATION

The probability that more leather will be sold does not signify a financial improvement in the tannery industry. In the past, the capital has increased at a greater ratio than the increase in the value of the products. The effect of this, as shown in Table III, is that in 1900 the amount of capital required for each $100 worth of goods produced was $85.35. In 1910, the capital necessary was $98.73. This decreases the net profits, as shown in Table IV, by 6.85 percent.

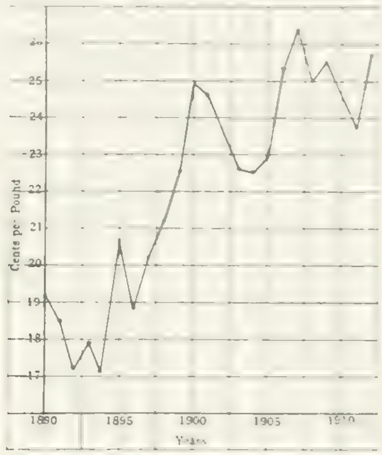


FIG. 3—CURVE SHOWING VARIATION IN YEARLY AVERAGE PRICE OF OAK SOLE LEATHER FROM 1890 TO 1912

When stockholders increase their investment in a company, they should earn at least the same percent dividends as formerly, otherwise their is no incentive to make the investment. If, in this decade the capital increases in the same proportion to the production as during the past, it will seriously interfere with the net profits. The problem before the tanners is how to increase the production in proportion to the increase in the capital, or better, how to increase the production with no material increase in capital.

TABLE V—COMPARISON OF POPULATION AND VALUE OF TANNERY PRODUCTS

Year	Population.		Value of Products.			
	Million Inhabitants	Percent Increase 10 Years	Total Value Millions	Percent Change in 10 Years	Value per Capita.	Percent Change per Capita.
[illegible]	31		$[illegible]		$2.41	
[illegible]	39	[illegible]	157	[illegible]	[illegible]	[illegible]
1880	50	29	[illegible]	[illegible]	4.00	[illegible]
[illegible]	[illegible]	25	172	[illegible]	[illegible]	31.0—
[illegible]	[illegible]	20	[illegible]	[illegible]	2.69	1.8—
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

THE SOLUTION

The tanners are not able to increase the selling

price of their product, which depends upon competition. The cost of raw materials and labor is dependent upon the supply and demand. The only means left to earn greater profit is through increasing the production and increasing the efficiency in the process

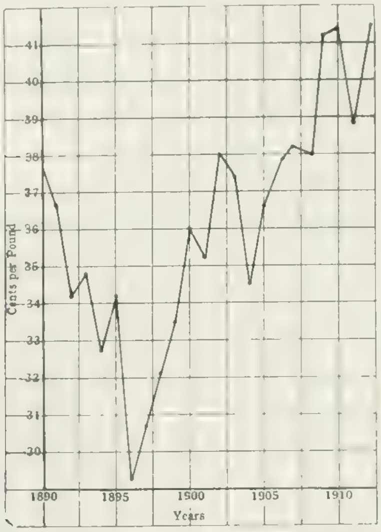


FIG 4—CURVE SHOWING AVERAGE PRICE PER YEAR OBTAINED FOR HEMLOCK SOLE LEATHER FROM 1890 TO 1912

of manufacturing. In this line the tanners have done remarkably well. Although the cost of hides and labor have increased, Table III shows that they have been able to reduce the total manufacturing cost.

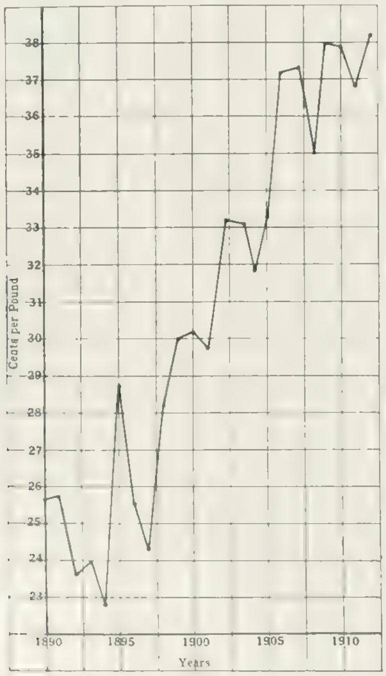


FIG. 5—CURVE SHOWING VARIATION IN THE AVERAGE PRICE OBTAINED FROM YEAR TO YEAR FOR OAK HARNESS LEATHER FROM 1890 TO 1912

This was accomplished by increasing their manufacturing efficiency.

AN OPPORTUNITY OVERLOOKED

An excellent opportunity exists in almost every tannery to effect savings, heretofore overlooked, in steam and power. Very few tanners are generating or using steam and power economically. The principal reason is because, in the past, they did not consider this item of expense sufficiently important. A few years ago fuel cost them very little as the spent tan provided them with the greater part. Today, extracts have come into such general use that it is necessary to purchase fuel for use in place of the spent tan.

In general the tanners have not considered using purchased power, believing that, inasmuch as they had to have steam, it was cheaper to make their own power. A large number of manufacturers in other lines have, however, found it more profitable to purchase electricity than to make their own power. One of the important reasons for this, other than the savings in power cost, is that it allows them to make extensions and increase power demand at a minimum investment. During the past few years a number of tanners also have closed down their steam engines

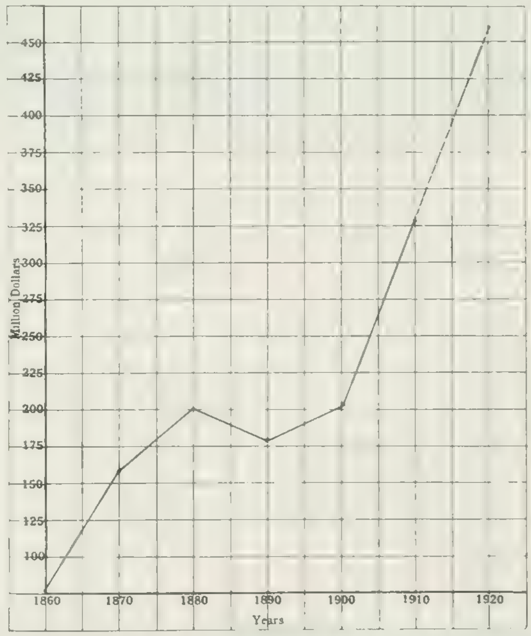


FIG. 6—CURVE SHOWING VALUE OF TANNERY PRODUCTS FROM 1860 TO 1910 WITH AN ESTIMATE TO 1920

and are now purchasing their power, operating their boilers at low pressures, for the steam necessary for manufacturing processes. In Table II it is shown that the primary horse-power increased 137 percent. Such an increase in the demand for power means that most tanners have found it necessary to add to the capacity of their power plants. Additions to a power plant are usually expensive and, as a rule, the money so invested could be made more profitable if used to manufacture leather. Also the industry is growing so fast that there is no assurance that further additions will not have to be made again in a few years.

To meet the conditions of increased power requirements is a subject that must be given considerable study. The solution may be by increasing the capacity of the present plant, by building an entirely new modern plant, or by purchasing central station power and using low pressure steam for manufacturing. Before deciding upon which plan is best for a particular case, the company should first secure the following data pertaining to the present plant:—

1—The total quantity of steam generated.
2—The total quantity of steam used for power.
3—The total quantity of steam used for manufacturing, and for heating.
4—The cost of steam per pound.
5—The quantity of power generated.
6—The cost of power per kilowatt-hour.

In addition to the above details, the investment which will take care of the immediate needs should be determined, at the same time considering what further investment will be required to provide for future growth. This analysis should show what money would be required for the isolated plant and what would be needed if power were purchased. The data pertaining to the present operation could be used as a basis to estimate the future cost of operation. When such an analysis as made the decision, in almost every instance, will be in favor of purchasing power.

TABLE VI—POWER REQUIREMENTS OF A TANNERY

Horse-power.	Motor R. P. M.	Drives.	Horse power Required.	
			Average	Max.
25	570	14 Shapley & Wells leather rolling machines 9 rollers working	21.5	
25	570	2 Extract wheels, 10 in. dia., 200 bellies in one wheel, 23 r. p. m.	16.1	22.8
20	570	2 Oil wheels, 10 in. dia., 200 bellies in one wheel 23 r. p. m.	16.1	24.1
10	1130	Buffing brush, 10 in. dia. by 24 in. long	2.34	
35	850	Fan	40	
20	850	2 No. 3 and 1 No 5 Turner setting machines, No. 5 machine working	10.7	12
15	850	2 No. 3 Turner setting machines		
		1 Leather roller		
		1 Setting machine only	6	
		Rolling machine only	2 7	
		Line friction	1.5	
15	850	Stick washing machines, not in use		
10	1130	Fans not in use		
		Beam house machinery		
30	850	2 Washing wheels, 19 r. p. m., 10 in. dia., 1 wheel only, load—20—60 lb. hides	18.8	21 [illegible]
5	850	Lime reel, 20 ft. long, made of wood. Could not test		
5	850	Lime elevator and mixer	1.6	
5	850	Small hair conveyor	1.67	
10	850	Leigen whole hide unhairing machine	10.7	12.1
15	850	8 Paddle wheels, 3 in use, 2 wheels running during test	1.34	
10	850	2 Liquor circulating pumps, 16 in. dia., suction, 4 in., discharge head, 16 ft	20	
5	850	200 Rockers, 188 rockers on during test	4	
35	570	150 Inch Turner fleshing machine	32.2	42 [illegible]

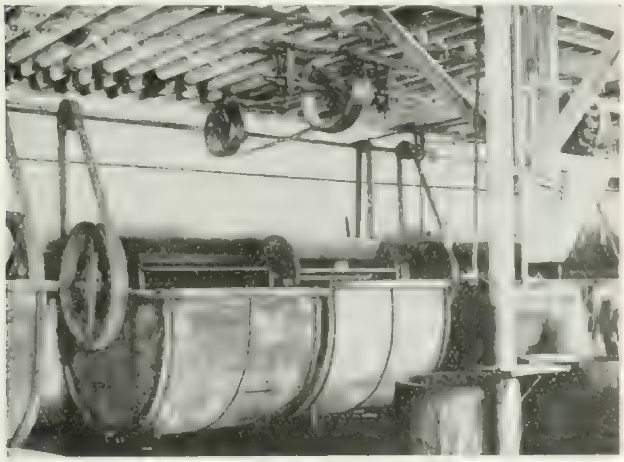


FIG. 7—FOUR TANNING TUBS DRIVEN BY A SINGLE FIVE HORSE-POWER MOTOR

Manufacturers in other lines have found that motors properly applied in their factories will increase the production of the machines. Proper layouts of motors in a tannery will allow the placing of the machines so that the materials can be handled with greater ease. This, together with other equally important advantages, will give the tanners a greater output. To the writer's knowledge these features increased the production for one particular tanner 15 percent, the investment required to make the changes being $7 000. The effect of a 15 percent increase in production on the profits can be readily determined by an analysis of the figures in Table II. In 1910, the value of the products was $356 772; an increase of 15 percent would make this figure $410 287. The cost of the materials was $270 162; an increase of 15 percent would be $310 686. The wages, salaries and miscellaneous expenses would remain the same. The total cost of production would be $366 530. The difference between the value of the products and the cost of production would be the profit, which would amount to $43 757. The capital was $352 117, which, plus the expense of $7 000 to change to electric drive, makes a total capital of $359 117. With a capital of $359 117 and a profit of $43 757, the percent profit is 12 percent. The percent profit in 1910, as given in Table II, was 8.77 percent; if this is increased to 12 percent it means that the percent profit has been increased 36 percent. In other words, a 15 percent increase in production means an increase of 36 percent in the profits.

FIG. 8—SKIN-SPLITTING MACHINES DRIVEN BY A FIVE HORSE-POWER MOTOR

FIG. 9—EMERY OR [illegible] WHEELS DRIVEN BY A FIVE HORSE-POWER MOTOR

Electric Locomotives Built in Large Quantities

G. PONTECORVO

DURING A VACATION IN EUROPE, the writer availed himself of the opportunity to visit the works of the Italian Westinghouse Company which are situated near the sea on the bay of Vado Ligure on the Italian Riviera. The Italian

FIG. 1—A VIEW SHOWING THE LOCATION AND BUILDING ARRANGEMENT OF THE PLANT OF THE ITALIAN WESTINGHOUSE COMPANY NEAR THE BAY OF VADO LIGURE ON THE RIVIERA

Company has specialized in the construction of large electric railway locomotives built mostly for the Italian State Railways. They manufacture many other lines of apparatus, but the production of locomotives was the most interesting feature of these works to the writer. Approximately 2 000 men are employed and they have been delivering, for quite a long time, locomotives of 2 000 to 2 600 horse-power

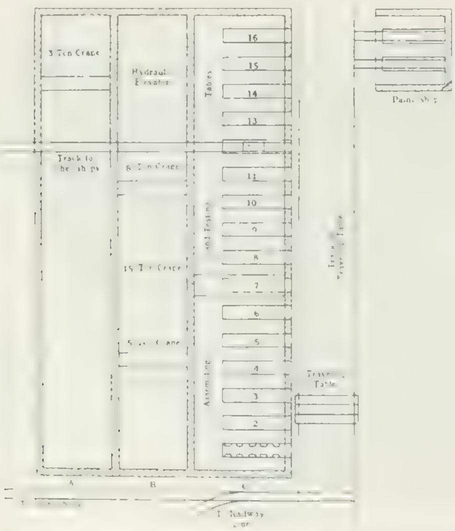


FIG. 2 PLAN OF LOCOMOTIVE SECTION OF THE SHOPS ASSEMBLING TABLES AND ACCESSORIES

at the rate of one every five days and they are expecting to keep up this production for many months. As they manufacture the complete locomotive, including electric motors and all mechanical parts, the production scheme in the shop must be very well arranged in order to obtain such results. The present layout of the works has been arrived at after some changes due to experience, and will probably be of interest, as even in this country a large production of electric locomotives of such size is not common.

In order to explain the arrangement used, the plan of the locomotive section of the shop is shown in Fig 2. It will be noticed that the locomotive shop consists of

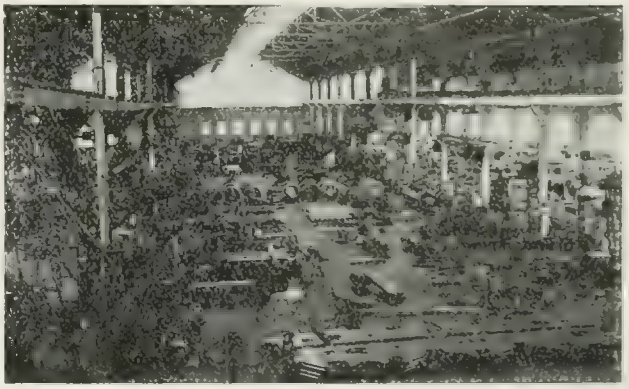


FIG. 3 CENTRAL AISLE OF LOCOMOTIVE SECTION WHERE ALL DETAIL PARTS ARE ASSEMBLED

FIG. 4—LOCOMOTIVE DETAILS IN THE PROCESS OF ASSEMBLING

Aisle *C* in the background showing locomotives nearing completion.

three large aisles, *A*, *B*, and *C*. The left one is given over to the manufacture of mechanical parts such as

frames, wheels, axles, etc. These parts, and all apparatus brought in from the other shops, such as motors, rheostats and control apparatus, are stored in the middle aisle, as shown in Figs. 3 and 4. The right aisle is used for the assembling of the locomotives, for which are provided numerous stands. The cranes are of small capacity, as a traveling table outside of the locomotive shop is used for moving the nearly completed locomotives from one stand to the other.

All of the assembling and testing of the locomotives is done on sixteen stands, situated in aisle *C*. Two heavy steel side plates, 328 by 48.6 by 1.2 inches, form the frame of the locomotives, the shaping of which is carried on by a combined milling, boring and slotting machine, which can shape six plates at a time, bolted together. On the first stands the plates are drilled and riveted to the cross plates. For this purpose there is a riveting machine suspended from above and a traveling drilling machine. On the floor there are blocks of cement, of the same shape as the bearings and at such a distance apart that the steel plates can easily be assembled by mounting them on these cement blocks. On the third and fourth stands the heavy cast and forged pieces are mounted on the frame as shown in Fig. 6. Along these two stands there are swinging drilling machines. On the fifth and sixth stands the body is completed, including the mounting of the bumpers and similar parts.

FIG. 5—THE BEGINNING OF THE ASSEMBLING AISLE
Showing in the foreground the cement blocks on which the steel plates are fitted for assembling and riveting.

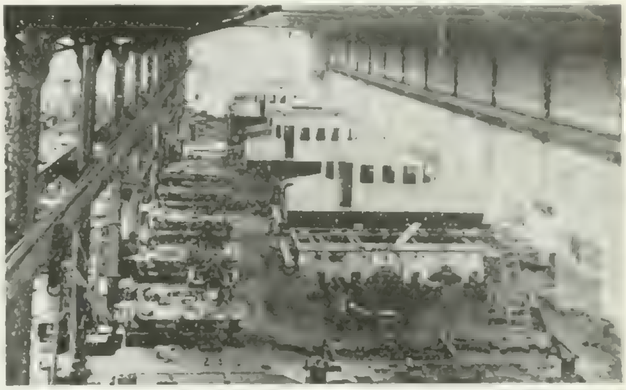


FIG. 7—GENERAL VIEW OF AISLE C SHOWING [illegible] TABLES AND THE DEVELOPMENT OF THE ASSEMBLING AS THE WORK PROGRESSES TOWARD THE END OF THE AISLE

FIG. 6—THE SECOND STAGE IN ASSEMBLING THE LOCOMOTIVE WHERE THE HEAVY CAST AND FORGED PIECES ARE MOUNTED ON THE STEEL FRAME

All of these first [illegible] stands are served by [illegible] ton crane. On stands seven, eight and nine the cab is mounted on top of the locomotive body and the whole mounted on wheels, the cabs being brought in from the outside by the traveling table. On stands *10* and *11*, the control apparatus and conduit and wiring are mounted. On stand *12*, the motors are mounted. This is done by means of an hydraulic elevator which lifts the motors under the body of the frame. The motors are brought in from the other shops by the track shown in the plan and the mounting of the motors by means of this elevator can be done in a very short time. Stands *13* and *14* are for the finishing of assembling, and *15* and *16* for testing of apparatus and for insulation tests. After painting, the locomotive is ready for shipment.

Fig. 7 gives a general idea of aisle *C* looking from the first stand and Fig. 8 shows the first of one order of 65 locomotives all of the same capacity and characteristics.

FIG. 8—A TYPICAL ELECTRIC LOCOMOTIVE BUILT BY THE [illegible] WESTINGHOUSE COMPANY

From the above description, it can be seen that there is no unnecessary shifting of locomotives or material and that all the work proceeds in parallel so that no delay occurs at any point, thus making possible a high rate of production.

Motors in the Portland Cement Industry

P. N. Harrison

THE CEMENT industry has grown enormously during the last twenty years. For example, the rate of increase in production for the period 1904-1909 was 146 percent, and for the three years 1909-1912 there was an increase of 26 per cent. A more definite idea of the rapid growth of this industry may be obtained from the following approximate figures:—

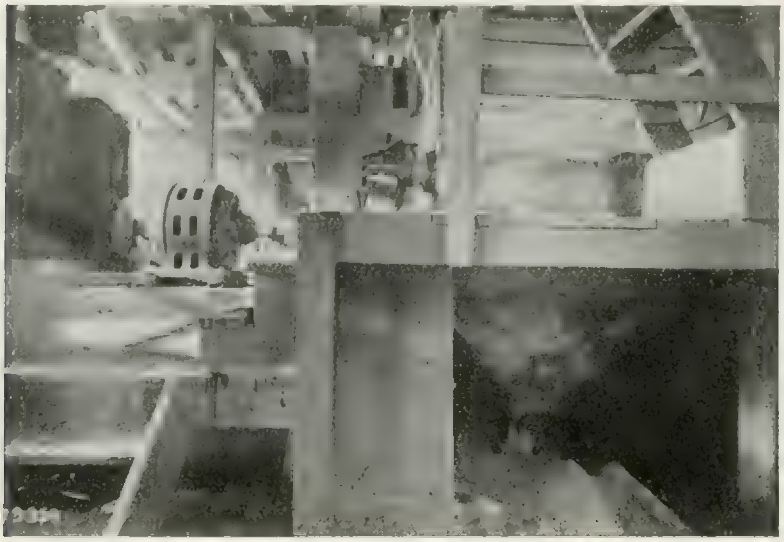


FIG. 1—BALL MILL

Coupled and geared to a 75 horse-power, 860 r.p.m., induction motor at plant of Superior Portland Cement Co., Concrete, Wash.

Year	Barrels Cement	Value
1895	990 324	$ 1 586 830
1904	26 505 881	23 355 119
1909	64 991 431	52 858 354
1911	78 000 000	66 250 000
1912	82 000 000	67 017 000

These figures are for Portland cement, the production of which is ordinarily 99 percent of the total cement production of the country, the other two forms being natural and puzzolan. While this marked growth has been the direct result of the natural demand for cement and the increased number of uses to which cement and cement products are being applied, it may be conservatively stated that the enormous increase in production has been considerably facilitated by the adoption of modern methods of power generation and distribution, which have simplified the complete manufacture of the product. The chief centers of the industry in the United States are in the East and Middle West. The Pacific Coast States also make a considerable showing, as a number of the largest plants in the country are now located in this section.

Portland cement is an artificial silicate, formed by mixing intimately a material having high lime content with clay or shale and properly fusing the mixture. The chemical make-up is approximately 62 to 65 percent lime, 20 to 23 percent silica and 8 to 10 percent alumina. There are three general combinations of ingredients, any of which when properly treated gives a good cement—cement rock and clay; limestone and clay, and marl and clay. Blast furnace slag is frequently substituted for the cement rock or marl, as it furnishes in varying percentages the desired silica and alumina.

The particular combination of ingredients used depends largely on the section of the country and the consequent nature of the supply. For example, in the Lehigh Valley District, limestone and and cement rock of a very high grade are obtained; in the Middle West, Michigan and Indiana, marl, because of its abundance, is used in conjunction with clay; in Western Pennsylvania, Indiana and other centers of the iron and steel industry, the limestone slag combination is used; while on the Pacific Coast the limestone and clay combination is more common.

In locating a new cement mill it is important to have the assurance of a supply of raw materials in the vicinity of the plant sufficient to last approximately twenty years. It is estimated that in the manufacture of one barrel of cement, about 450 pounds of limestone and 150 pounds of clay or shale are consumed, which, for a mill having an output of 1 000 barrels per 24 hours, means 66 000 tons of limestone and 22 000 tons of clay or shale per year. In other words, 20-000 000 cubic feet of limestone and 5 000 000 cubic feet of clay or shale should be available for a thousand-barrel mill if a heavy investment on such a plant is to be warranted.

FIG. 2—KRUPP BALL MILL

Belted to a 75 horse-power induction motor at plant of the Southwestern Portland Cement Co., El Paso, Texas.

PROCESS OF MANUFACTURE

There are two processes of making Portland cement, namely, the dry process and the slurry or wet

process, each of which calls for the same chemical ingredients, differing only in the state in which the raw

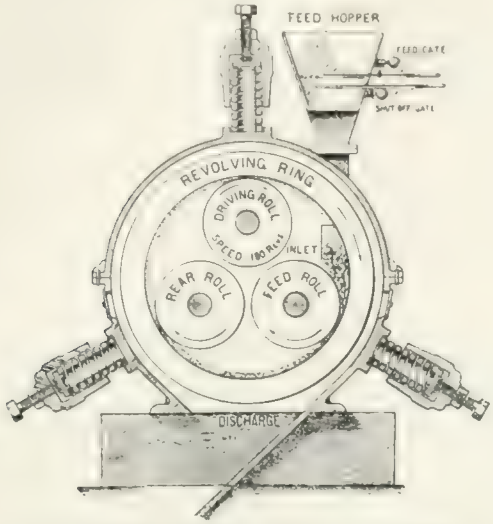


FIG. 3—CROSS-SECTION VIEW OF A KENT MILL

materials are found and the way in which they are treated during the stages of manufacture. The dry process is by far the more common. The following description of the dry process contemplates the use of limestone and clay as raw materials, and the three installations outlined later are examples of such practice.

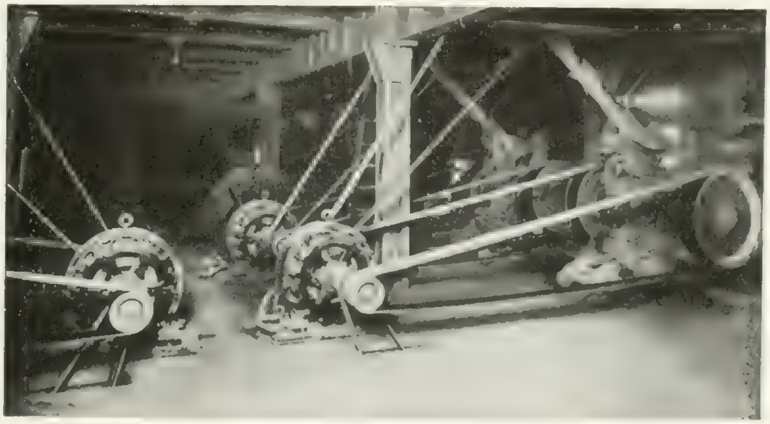


FIG. 4—GROUP OF KENT MILLS

Driven by 40 horse-power squirrel-cage motor. At plant of Chicago Portland Cement Co., Chicago, Ill.

The raw materials are conveyed from the quarries, sometimes adjacent to, but often three to five miles distant from the mills, to storage hoppers above the plant so as to afford a gravity flow of material to the first step in the process—the crushers. The limestone and clay are fed to separate crushers of the gyratory type; although rolls are frequently used to crush the clay or shale. From the crushers the materials are fed to separate cylindrical rotary dryers which are lined with fire brick. They range in size from four to six feet in diameter and from 30 to 60 feet in length, are slightly inclined to the horizontal and rotate at from three to ten revolutions per minute. These dryers are fired with pulverized coal or crude oil as the location of the plant dictates and dry the materials thoroughly during the passage from the upper to the lower end, preparatory to the next stage in the process, known as intermediate grinding.

After drying, the materials are ground to approximately 30 mesh in one of several types of machines, such as the ball mill, the Kent mill, or the Williams hammer mill, all of which perform the same duty. The ball mill and the Kent mill are more commonly used, the former being a slow speed machine running at approximately 25 r.p.m., while the latter rotates at about 200 r.p.m.. The ball mill employs a heavy charge of steel balls which fall over overlapping plates on the sides of the mill, thereby grinding the material. Typical ball mill drives are shown in Figs. 1 and 2. The principle of operation of the Kent mill may be seen from the cross-section view in Fig. 3, and an installation of Kent mills is shown in Fig. 4. The two raw materials, after having been treated separately up to this stage, are now united in definite proportions in automatic scales, a typical mixture being 1 245 pounds limestone and 260 pounds clay.

After leaving the automatic scales, the fine grinding of the material is usually accomplished in tube mills, Fuller mills or Griffin mills. While the tube mills are by far the most common, the other types are much in favor in certain mills. The most popular size of tube mill is 5.5 feet in diameter by 22 feet long, rotating at 24 r.p.m., the mill being filled to about the center line with a five to seven ton charge of flint pebbles, two to three inches in diameter. When the material is fed into one end of the tube mill, it is gradually pulverized and passes to the discharge end. The fineness of product is governed by the rate of feed and the charge of pebbles, and will average 92 percent through a 100 mesh screen.

The Fuller and Griffin mills perform this same operation by means of

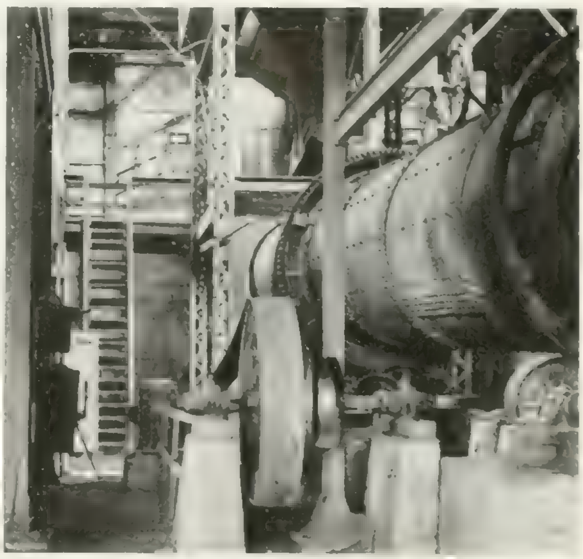


FIG. 5—ROTARY DRYERS

Two dryers driven by a 30 horse-power induction motor. At plant of the Allentown Portland Cement Co., Evansville, Pa.

heavy steel balls (Fuller mill) or a roll (Griffin mill), working against a stationary die by means of centrifugal force, thereby necessitating the relatively high speed of approximately 200 r.p.m.

The completion of the fine grinding concludes what is known as the raw mill process. Following the fine grinding the material is transferred to the kiln building, where it is burned in rotary kilns. These are slow revolving furnaces on a slight incline to the horizontal and approximately eight and one-half in diameter by 125 to 150 feet long. Material fed in at the upper end gradually works down towards the lower end, due to the rotating of the kiln, the speed ranging from one turn in 45 seconds to one turn in two minutes. The heat is applied at the lower end of the kiln and is drawn the entire length into the atmosphere by means of a properly arranged stack. Thus, the material is subjected to a gradually increasing temperature until it reaches the maximum at the lower end. This range of temperature is roughly estimated at from 700 degrees F. at the stack end to 2 800 to 3 300 degrees F. at the finish end. The discharge from the kiln is in the form of a globular clinker which is passed either to a cooler or direct to storage bins for weathering.

In continuing the process in what is termed the finish side of the mill, it is sometimes necessary to dry the clinker when taken from storage. It is then passed through an intermediate grinding and also a fine grinding process, using the same types of machines as on the raw side of the mill, namely, ball mills for the intermediate, and tube mills for the fine grinding, or some other combination, such as, Sturtevant ring roll mills for intermediate and tube mills for fine grinding; Kent mills for intermediate and Fuller mills for fine grinding, etc. Previous to the fine grinding of the clinker, two percent of pulverized gypsum is added to regulate the setting quality of the finished product. This is of such fineness that 95 percent or more will pass through a 100 mesh screen, and 75 to 80 percent through a 200-mesh screen. The product is then conveyed to the stock house for storage in bulk or packed in sacks of 95 pounds, or barrels of 380 pounds for shipment.

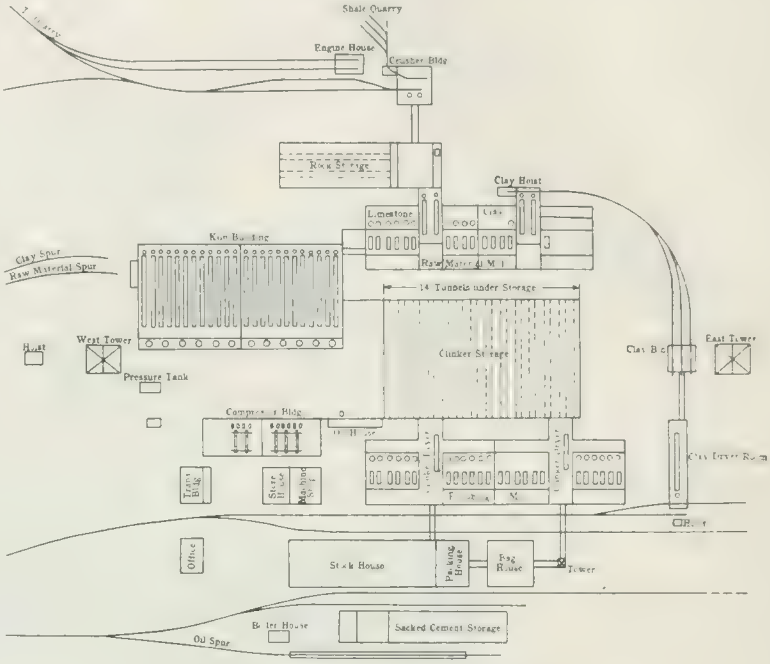


FIG. 6—TYPICAL CEMENT MILL LAYOUT

FIG. 7—250 HORSE-POWER, 345 R.P.M., INDUCTION MOTORS

Each belted to two 5.5 by 22 ft. finish tube mills in adjoining room. At the plant of the Santa Cruz Portland Cement Co., Davenport, Calif.

In the foregoing outline it is to be understood that all steps in the manufacturing process are linked together by means of belt or screw conveyors, screens for returning over-sized material for regrinding, and temporary storages for material, so arranged as to relieve any stage in the process of congestion during slight choking of any of the apparatus.

In addition to the processes as outlined, there are miscellaneous adjuncts to a complete mill which are common to many other industries, such as hoists, air compressors to give blast to fuel in dryers and rotary kilns, blowers, pumps, laboratory apparatus, repair shops, etc. Where coal is used for fuel, pulverizers are necessary to powder the coal to 90 percent through a 100-mesh screen. Fig. 6 illustrates the "flow sheet" of a very large cement mill in the West, conspicuous for having standardized on ball mills and tube mills in the intermediate and fine grinding departments for both the raw and the finish sides. This plant is described in detail as plant "A" later in this article. It purchases all of its power from a local central station. The combinations of machines used in several actual cement mills in scattered localities are shown in Table I.

POWER CHARACTERISTICS

The mention of cement mill motor service immediately suggests machines of most rugged character-

istics with dust proof features. Motor manufacturers have found it desirable to develop a line of induction motors especially suited to this class of work. In general, cement mill apparatus is is operated at constant speed. The exceptions to the rule are found in the hoist applications, common about the quarry and the mill proper, and the rotary kiln and dryer drives.

Since the various machines are of large and bulky proportions, of great inertia and subject to overloads due to clogging of materials, the motor power must be capable of exerting high starting torque and must have sufficiently large full-load and pull-out torques to serve all emergencies in the long hours of severe service characteristic of this class of apparatus. This is especially true of ball mills and tube mills, in which heavy rotating parts, along with heavy charges of abrading agents and actual charges materials must be turned over. There are other constant speed machines, the operation of which is aided considerably by their own fly-wheel effect, such as those operating on the centrifugal force principle, as does the Fuller mill and the Griffin mill, as well as still others which make use of an externally applied fly-wheel, such as the Williams pulverizer, the jaw crusher and the gyratory crusher. Machines of this type require high torque at start and are commonly driven by motors whose slip characteristics afford this torque as well as the proper utilization of flywheel effect. Simplicity of construction, absence of contact between moving parts and general ruggedness make the squirrel cage induction motor a favorite for most applications.

TABLE I—DATA ON CEMENT MILL INSTALLATIONS

MILL NO. I

Raw Mill	*Clinker Department*	*Finish Mill*
a—Gyratory crusher	[illegible]	[illegible]
b—Rotary dryers	[illegible]	[illegible]
c—Ball mills (intermediate)	[illegible]	[illegible]
d—Automatic scales		[illegible]
e—Tube mills (fine grinding)		

DISTRIBUTION OF POWER IN MILL NO. I

Raw mill	[illegible]	motors,	aggregating	[illegible] horse-power
Coal house	[illegible]			[illegible]
Clinker house	[illegible]	"	"	[illegible]
Finish mill	[illegible]	"	"	[illegible]
Machine shop	[illegible]	"	"	[illegible]
Pump house	2	"	"	[illegible]
Power house	4	"	"	420
Total	92			3865

MILL NO. 2—CAPACITY [illegible] BBLS. PER YEAR

Raw Mill	*Clinker Department*	*Finish Mill*
a—No. 5 Symons crusher	a—Williams mills for crushing coal	[illegible]
b—No. 6 Symons crusher	b—Smidth No. 16 tube mill	[illegible]
c—Ruggles Coles rotary dryers	c—Clinker storage	c—Storage and packing department
d—36 × 42 in. Jeffrey mills	d—Rotary kiln (coal fired)	
e—Williams hammer mill		
f—Smidth No. 8 tube mills		

Mill No. 2 purchases power from Central Station for 2 030 horse-power in motors and produces a barrel of finished cement on a consumption of 18.2 wilowatt hours.

MILL NO. 3—CAPACITY 2 372 500 BBLS. PER YEAR

Raw Mill	*Clinker Department*	*Finish Mill*
a—Gyratory crushers	a—Rotary kilns (coal fired)	a—Ball mills
b—Rotary dryers	b—Clinker storage	b—Tube mills
c—Ball mills		c—Storage and packing department
d—Tube mills		

Mill No. 3 purchases power for approximately 8 165 horse-power in motors and finishes a barrel of cement on a consumption of 16.24 kilowatt hours.

MILL NO. 4—CAPACITY 300 000 BBLS. PER YEAR

Raw Mill	*Clinker Department*	*Finish Mill*
a—[illegible] mills	a—[illegible] ft. rotary kilns	a—No. [illegible] Kominuters
b—6½ × 60 ft. rotary dryer	b—6½ × 60 ft. [illegible] clinker cooler	b—[illegible]
c—No. 85 Kominuters	c—Clinker storage	c—Storage and packing department
d—6 × 22 ft. tube mills		
e—5 × 22 ft. tube mills		

DISTRIBUTION OF POWER IN MILL NO. 4

Mill No. 4 purchases power for approximately 1 668 horse-power in motors and produces a barrel of cement on a consumption of 24.6 kilowatt hours.

	Horse-Power Connected	Horse-Power, Max. Demand
a—Rock crushing and drying	[illegible]	[illegible]
b—Raw intermediate grinding	245	266
c—Raw fine grinding	457	[illegible]
d—Coal grinding	160	141
e—Clinker burning	120	[illegible]
f—Finish intermediate grinding	168	167
g—Finish fine grinding	400	[illegible]
h—Mechanical department	60	[illegible]

NOTE.—The above table is simply intended to give a brief summary of the combinations of the chief apparatus which are used in various mills and gives no consideration to miscellaneous apparatus such as conveyors, elevators, screens, etc. Where coal is used for fuel the coal grinding and pulverizing apparatus is included under the clinker department.

*A Kominuter is a special type of ball mill.

For hoist service, however, varying speed slip ring induction motors are preferable, for reasons common to any hoisting problem.

The other exception to the rule for constant speed service—the rotary kiln—is a result, not of inherent characteristics of the kiln, but rather of the duty performed. In other words, it is necessary to vary the temperature in the kiln to produce a proper fusion of the mixture, and it has been found preferable to vary the speed of rotation of the kiln rather than the rate of feed of material or fuel to the kiln. The rate of turning governs the time it takes the mixture to pass through the kiln and this governs the degree of fusion to give the desired clinker product. This requirement is readily met by the use of varying speed slip-ring induction motors, arranged with controllers suitable for continuous operation on any point between one-half and full speed.

The method of drive in a cement mill is perhaps of greatest importance when considering motor applications, for with the prevalent cement dust and frequent high temperature, coupled with the nature of the apparatus to be driven the success of the drive is largely dependent on this consideration.

Where possible, the motors should be installed in a room separate from the driven machine. It is customary to drive crushers, together with their respective elevators and conveyors, by individual belt drive; while the various types of raw, intermediate and finish grinders are advantageously belt driven, through flexible couplings, individually or in groups of two, a scheme which brings into play a short counter-shaft and makes standard speed squirrel-cage induction motors applicable.

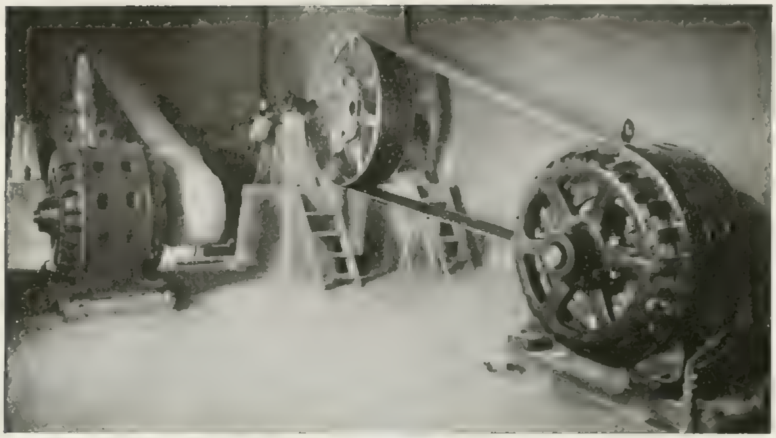


FIG. 8—150 HORSE-POWER INDUCTION MOTORS

Each belted to a tube mill in the adjacent room. At the plant of the Texas Portland Cement Co.

Tube mills, either in the raw or finish mill, should invariably be driven by individual motors, either direct connected to the shaft by flexible couplings or belted to the counter-shaft of the mill. Flexible couplings are essential when a direct connected drive is employed. Clutch pulleys are not necessary on the belted drives providing the proper motor is applied. Experience has shown that the rotary kiln drive is best accomplished by individual motor and belt. The motor is usually placed in a pit under the kiln, and near its middle. This arrangement takes the motor away from the high temperatures and at the same time does not interfere with the location of its controller at the clinker or finish end of the kiln.

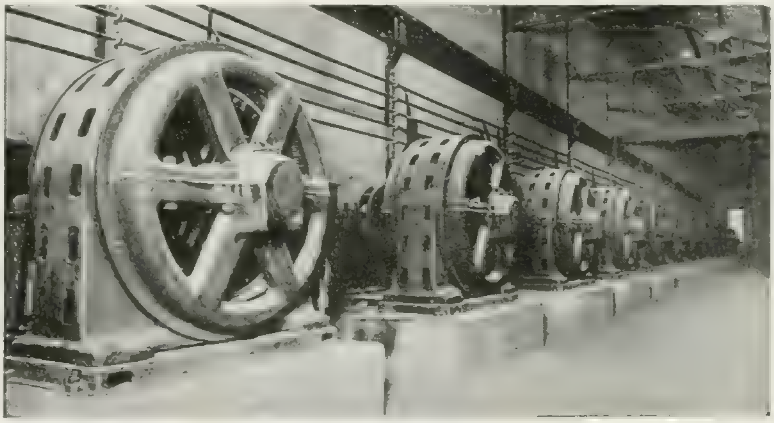


FIG. 9—A ROW OF 150 HORSE-POWER, 160 R.P.M., INDUCTION MOTORS

Each flexibly coupled to a tube mill in the adjoining room. At the plant of the Universal Portland Cement Co.

Rotary dryers for either raw materials or clinker are seldom more than one or two in number and are very readily driven individually, together with their conveyors and elevators. While it is frequently possible to group the various conveyors and elevators directly on the machines which they serve, it is at times necessary to group them with the Newago screens on separate drives. The packing machines and auxiliary conveyors are usually on one motor, while the miscellaneous machines, such as air compressors, pumps, hoists, etc., are all individually driven.

Thus it is seen that the modern cement mill is largely individually driven, as this method, by the use of standard squirrel-cage motors, makes possible, with the exceptions noted, a most economic method of operation.

While the cement mill has not ordinarily been considered within the field of operation of the central station, a considerable number of such plants are being successfully served from power lines, and the three plants for which detailed figures are given are all interesting examples of central station power in the cement mill. Attractive rates must be part of the power solicitor's ammunition if he wishes to deal successfully with the cement manufacturer, while continuity of service, twenty-four hours a day, seven days a week is an absolute necessity. The use of large squirrel-cage motors should prove no barrier to the securing of such load, since the central station and the consumer should appreciate that the ratio of any one motor to the total capacity is very small. Long hours of continuous operation of all machines give an average power demand that is only slightly lower than the maximum, and thus a very high load factor is characteristic of cement mill operation. The motor capacity installed per barrel of cement manufactured per day will be from one to one-half horse-power; while the power consumed per barrel of cement will range from sixteen to twenty-five kilowatt-hours.

The question of power requirements of the various machines depends on several items, such as the nature of raw material, the rate of feed and, for crushing or grinding apparatus, the size to which the mate-

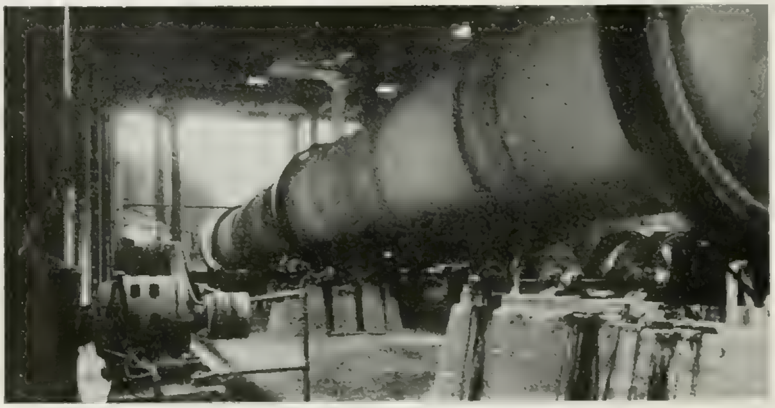


FIG. 10—TWO 8 BY 120 FT. ROTARY KILNS

Driven by a 50 horse-power, 850 r.p.m., induction motor. At the plant of the Superior Portland Cement Co., Concrete, Wash.

rials are reduced and the type of machines used. Table II gives approximate horse-power and other characteristics of the principal machines, as well as the recommended method of drive.

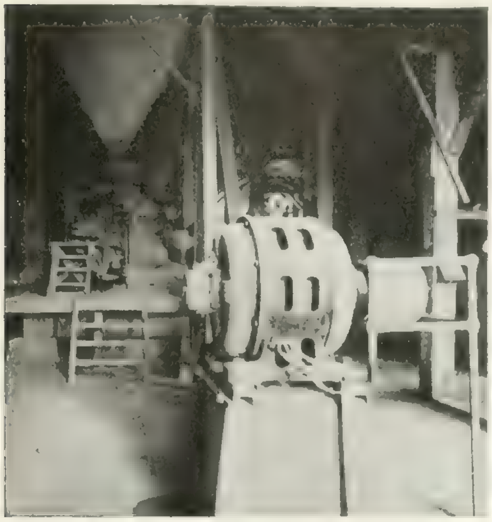


FIG. 11—RING ROLL MILL

Belted to a 75 horse-power, 860 r.p.m., induction motor. In the finish mill of the Superior Portland Cement Co., Concrete, Wash.

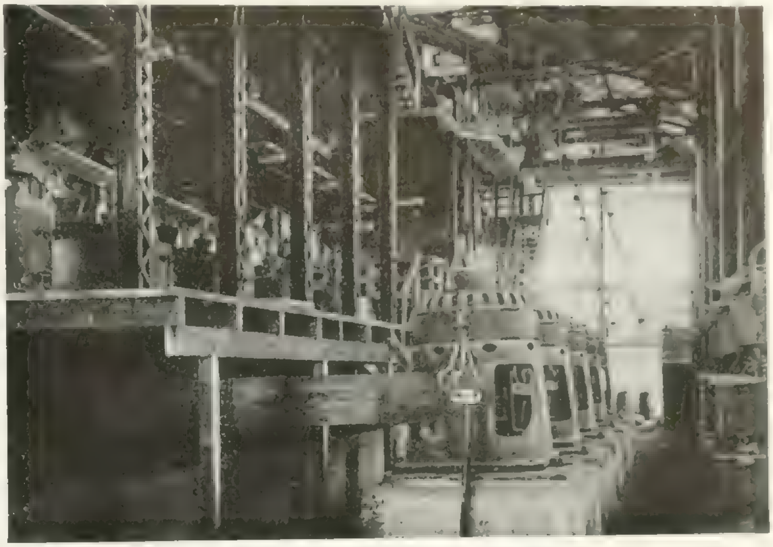


FIG. 12—GROUP OF 48-INCH FULLER MILLS

Each belted to a 75 horse-power, 480 r.p.m., vertical induction motor. Motor pulley, 20 by 18 in., mill pulley, 54 by 18 in. At the plant of the Allentown Portland Cement Co.

TABLE II—CHARACTERISTICS OF CEMENT MILL MACHINERY.

Machine	R.P.M. of Machine	Capicity per hour	Starting Torque (Times Full Load)	Method of Drive	Horse-Power for Average Size Used
Gyratory Crusher	300-400 (Driven pulley)	5 to 1500 tons	2	Belted	50–150
Rotary Dryer	3-10	8-20 tons	2	Belted	30 Incl. conveyors
Ball Mill	20-25		2	Belted or flexibly coupled	50-75
Williams Mill	100-11000	16-20 tons (12 mesh) 15-18 tons (20 mesh)	$1\frac{1}{2}$	Flexibly Coupled	75-200
Kent Mill	200	6-8 tons (20 mesh)	1	Belted (2 belts	40
Fuller Mill	33 in.—210 42 in.—160 54 in.—125	4 tons $2\frac{3}{4}$ to 3 tons	$1\frac{1}{4}$	Belted to vertical motor	25-40 75-90 150-200

Machine	R.P.M. of Machine	Capacity per hour	Starting Torque (Times Full Load)	Method of Drive	Horse-Power for Average Size Used.
Griffin Mill	"Giant" 160-170 30 in.—200 36 in.—150	13-15 bbls. $1\frac{1}{2}$ to $2\frac{1}{2}$ tons $1\frac{1}{2}$ to $2\frac{1}{2}$ tons	$1\frac{1}{2}$	Belted	40-50
Sturtevant Mill	330 (Driven pulley)	45 bbls. 20 mesh 25 bbls. 80 mesh.	$1\frac{1}{2}$	Belted	50-60
Tube Mill $5\frac{1}{2}$x22 ft.	24	Depends on speed and charge of pebbles	2	Belted to counter-shaft or flexibly coupled	100-150
Kiln	0.6 to 2 r.p.m	Average 25 bbls.	2	Belted individually	[illegible] per Kiln
Sacker	[illegible]60 (Driven pulley)		1	Belted in group	Approx. [illegible] hp. per machine, incl. conveyors.

No figures are given for conveyors, elevators, pumps, or compressors, etc., as these are purely local considerations and are treated differently in every installation.

PLANT A

This plant has a capacity of 9 000 bbls. of cement on the finish side and 6 000 bbls. of clinker on the raw side per 24 hours. The raw materials are obtained in electrically operated quarries about three miles distant and are brought to the plant by steam power. An average of 500 men are employed to operate the mill and quarry, working in two 12 hour shifts.

An aggregate of 10 980 horsepower in induction motors is installed, having a load factor of [illegible]3.4 percent. The supply source is three-phase, 2 200 and 440 volts, 60 cycles. The electrical energy consumption per barrel manufactured is 16.7 kw-hrs.

MOTOR APPLICATION

QUARRIES

No.	Hp.	R.P.M.	Type	Application
1	95	685	Slip Ring	Geared to a single drum hoist
1	150	580	Squirrel Cage	Driving a Gates No. 9 gyratory crusher
1	50	850	Slip Ring	Geared to a Vulcan Iron Works single drum hoist
1	150	690	Slip Ring	Geared to an S. Flory 3 drum hoist
				CLAY DRYING AND GRINDING
1	40	850	Squirrel Cage	Belted to a clay dryer and belt conveyor to storage bin.
1	95	690	Slip Ring	Geared to an S. Flory single drum hoist operating a 3 ton car over a 1000 ft. slightly curved track, up slight incline from [illegible] to [illegible] dryer
1	150	345	Squirrel Cage	Belted to 35 ft. of shafting, driving a Vulcan Iron Works, 100 ft. rotary drum 6 ft. diam. small end, 7 ft. diam. large end. Also conveyors and elevators handling clay to and from dryer
1	150	345	Squirrel Cage	Coupled to an 8 ft. shaft (two hangers) and belted to a ball mill
				ROCK DRYING AND GRINDING
1	150	580	Squirrel Cage	Coupled to a 15 ft. shaft (five hangers)—connected load:— Two Gates No. 6 gyratory crushers; One 24 in. x 200 ft. belt conveyor from crusher to storage house; Two 20 in. x 35 ft. belt conveyors with automatic trippers to storage house
1	75	1130	Squirrel Cage	Coupled to a Williams No. 5 limestone crusher
1	30	850	Squirrel Cage	Belted to a shafting driving three belt conveyors in storage house
1	150	345	Squirrel Cage	Belted to 35 ft. of shafting driving two Mosser 7x60 ft. rotary dryers $3\frac{1}{2}$ r.p.m. Also drives elevators and conveyors from storage to dryers and then to ball mills

5	150	345	Squirrel Cage	Each coupled to a short shaft, to which are belted two ball mills, 22 r.p.m.
1	150	345	Squirrel Cage	Belted to shafting driving screw conveyors under clay and limestone bins, mixing conveyors and elevators to raw tube mills
7	250	345	Squirrel Cage	Each coupled to a short shaft, to which are belted two 5½x22 ft. tube mills, 26 r.p.m.
1	75	690	Squirrel Cage	Coupled to a short shaft—connected load:— One elevator to top of kiln building One screw conveyor over kiln bins One screw conveyor from raw mill to kiln building
14	30	690	Slip Ring	Each belted to 7x125 ft. rotary kiln. Driven pulley, 80x12 in.; motor pulley, 20x10 in.
1	40	580	Squirrel Cage	Belted to 125 ft. shaft driving seven 12 in. x 30 ft. elevators to clinker coolers
1	30	850	Squirrel Cage	Belted to an S. Howes packer

CLINKER HANDLING

1	110	675	Slip Ring	Geared to an S. Flory double drum hoist operating cable with 30 bbl. skip on 900 ft. aerial tramway
1	150	690	Slip Ring	Geared to a Lidgerwood double drum hoist operating a duplicate skip
1	150	345	Squirrel Cage	Belted to shafting—connected load:— Fourteen 24 in. x 205 ft. belt conveyors One 24 in. x 150 ft. belt conveyor Three bucket elevators One clinker dryer
1	150	345	Squirrel Cage	Belted to 35 ft. of shafting driving a Mosser 7x60 ft. rotary dryer, 3½ r.p.m., also three elevators to dryer, ball and tube mills
9	150	345	Squirrel Cage	Each coupled to a short shaft, to which are belted two ball mills
2	150	345	Squirrel Cage	Each coupled to a short shaft, to which is belted a Gates No. 5 gyratory gypsum crusher and two belt conveyors to stock house bins
10	250	345	Squirrel Cage	Each coupled to a short shaft, to which are belted two 5½x22 ft. tube mills, 25 r.p.m.
1	75	690	Squirrel Cage	Belted to line shaft, driving two 14 in. x 250 ft. screw conveyors under cement storage bins Two elevators to packers Eight S. Howes packers
1	10	1120	Squirrel Cage	Belted to a 20 ft. shaft driving two rotary sack cleaning drums

COMPRESSOR HOUSE

1	800	195	Squirrel Cage	Coupled to an 85 ft. shaft—connected load:— Two Ingersoll Rand, Class D, 24x24 in. duplex air compressors. Flywheel, 12 ft. diam., rim 46 in. x 3½ in., 100 r.p.m. Supplies 1728 cu. ft. air per min. at 80 lbs. pressure One Ingersoll-Sargent 25¼x16¼x16 in. compound air compressor 125 r.p.m. Supplies 1 200 cu. ft. of air per min. at 80 lbs. pressure Six P. F. Sturtevant No. 9 blowers, 1 200 r.p.m. Supply air to clinker cooling towers
1	800	195	Squirrel Cage	Coupled to a 15 ft. shaft driving two Ingersoll Rand, Class D, 24x24 in. duplex air compressors. Duplicate of above

REPAIR SHOP

1	30	840	Squirrel Cage	Belted to line shaft—connected load:— Two 20 in. lathes One double emery wheel One 12 in. hack saw One Long & Allstatter 12 in. shear One set 7 ft. bending rolls One Forbes pipe threader One wheel press

MISCELANEOUS

2	15	1120	Squirrel Cage	Each geared to a triplex plunger crude oil pump
1	15	840	Slip Ring	Direct connected to a 4 ft. exhaust fan
1	3	1700	Squirrel Cage	Belted to a portable stacker
1	½	1700	Squirrel Cage	Belted to a Starke centrifuge
1	5	1720	Squirrel Cage	Belted to a line shaft driving a small crusher and grinder in sample mill
1	1	1700	Squirrel Cage	Belted to line shaft driving a small emery wheel and small bench lathe

POWER CONSUMPTION—1912

Month	Kw-Hrs.	Bbls. of Clinker Burned*	Bbls. of Cement Manufactured	Month	Kw-Hrs.	Bbls. of Clinker Burned*	Bbls. of Cement Manufactured
January	402 000	......	43 210	July	1 812 000	97 319	87 345
February	858 000	......	83 110	August	2 008 000	96 540	106 000
March	1 348 000	2 457	140 150	September	1 744 000	96 240	85 495
April	2 196 000	70 131	135 110	October	1 978 000	96 810	131 047
May	2 042 000	110 683	79 575	November	1 966 000	95 280	114 527
June	1 690 000	92 927	84 075	December	1 692 000	71 130	96 275

*The clinker storage is usually so large that the number of barrels of clinker burned and barrels of cement manufactured bear no direct relation to each other in any one month.

PLANT B

This plant has a rated capacity of 2 500 bbls. of cement per 24 hrs. The clay and limestone is obtained from an adjoining quarry, the material being hauled in small cars up an incline from the pit. There are 250 men employed in the quarry and mill, working in 12-hr. shifts.

An aggregate of 3 685 horse-power in squirrel-cage induction motors is installed, having an average demand during normal operation of 2 200 kw and a load factor of 36.5 percent. The supply source is three-phase, 2 000 volts, 60 cycles. The electrical energy consumption per barrel of cement manufactured is 23.4 kw-hrs.

MOTOR APPLICATIONS

QUARRY

No.	Hp.	R.P.M.	Application
1	15	1120	Driving a single drum hoist with 1 in. cable, to draw cars up incline from pit
1	15	1700	Duplicate of above drive
1	50	850	Driving a similar cable haul
1	15	1700	Direct connected to a 4 in. centrifugal drainage pump, operating against a 75 ft. head

COMPRESSOR ROOM

1	306	345	Belted to an Ingersoll Rand 2 cylinder, compound horizontal air compressor, which carries 100 lbs. pressure. Flywheel, 12 ft. diameter, rim 26x2 in., 96 r.p.m. Supplies air for drills in quarry and to burners under kilns and dryers

MILL

1	150	850	Belted to a Gates No. 9 gyratory crusher, driven pulley 54x20 in., motor pulley 22x20 in. Motor also drives a 20 in. x 40 ft. incline conveyor from crusher to bin
1	15	1135	Belted to an 8 ft. shaft (two hangers) driving a 20 in. x 45 ft. conveyor
1	10	1120	Driving a 24 in. x 200 ft. conveyor
1	200	580	Belted to a 50 ft. shaft—connected load:— Two Gates No. 5 crushers Two 6x35 ft. rotary dryers Two bucket elevators Two drag conveyors
1	50	850	Belted to a Gates No. 5 crusher. Driven pulley, 36x16 in., motor pulley, 16x16 in. Motor also drives a 16 in. x 60 ft. bucket elevator
1	40	850	Belted to a 7x60 ft. crushed rock dryer. Driven pulley, 24x12 in., motor pulley, 15x12 in. Motor also drives a 20 in. x 45 ft. inclined conveyor and a 16 in. x 45 ft. elevator
1	150	345	Coupled to a 20 ft. shaft—connected load:— Two Williams No. 5 crushers, driven pulley, 20x15 in., driving pulleys, 72x15 in. One 16 in. x 65 ft. elevator Two Newago screens
1	50	850	Belted to a 12 ft. shaft—connected load:— Two 12 in. x 100 ft. screw conveyors Two automatic scales Two 16 in. x 75 ft. elevators One Mixer

1 75 690 Belted to a 50 ft. shaft—connected load:— [illegible]
- One [illegible] triplex pump, [illegible]
- Ten 60 ft. rotary kilns
- One Ingersoll Sergeant Drill Co. 2 [illegible]

1 800 195 Coupled to a [illegible] shaft, which is [illegible]—connected load:—
- [illegible]
- Six 5x22 ft. raw tube mills
- One Ingersoll Sergeant Drill Co. 2 cylinder, horizontal air compressor
- Friction load, motor and shafting, 122 hp.
- Load on motor with compressor working, [illegible]
- Average power required by one ball mill with its conveyor, 31 hp.
- Average power required by one tube mill with its conveyor, 79 hp.

1 150 580 Belted to countershaft on a 5x22 ft. tube mill, driven pulley 104x24 in., motor pulley, 28x24 in.

1 50 850 Coupled to a 6 ft. shaft, belted to a 30 ft. countershaft—connected load:—
- Two 8x125 ft. rotary kilns
- One B. F. Sturtevant 60 in. exhaust fan

1 15 1120 Belted to an 8 ft. shaft—connected load:—
- One 20 in. x 150 ft. belt conveyor from kiln room to clinker storage
- One 12 in. x 75 ft. clinker elevator

CLINKER HOUSE

1 10 1120 Driving a 20 in. x 225 ft. conveyor with automatic trippers and a 12 in. x 65 ft. bucket elevator

1 5 1120 Direct connected to a 30 in. exhaust fan

FINISH MILL

1 40 870 Belted to a shaft—connected load:—
- One 5x45 ft. clinker dryer
- One 12 in. x 45 ft. elevator
- One 20 in. x 400 ft. belt conveyor from storage to dryer
- One 20 in. x 35 ft. conveyor

1 30 850 Belted to shaft—connected load:—
- One 20 in. x 100 ft. belt conveyor
- One 12 in. x 45 ft. elevator
- One 20 in. x 150 ft. belt conveyor

1 5 1120 Belted to shaft—connected load:—
- One 12 in. x 60 ft. elevator
- One 16 in. x 30 ft. belt conveyor

1 40 850 Belted to a 6 ft. shaft driving a Joshua Hendy Iron Works 24x12 in. roll gypsum crusher

2 250 345 Each coupled to a 6 ft. shaft driving two 5 ft. 6 in. x 22 ft. tube mills

1 800 195 Coupled to a 45 ft. shaft, to which is belted a 65 ft. countershaft—connected load:—
- Six finish ball mills
- Six 5½x22 ft. finish tube mills
- One 14 in. x 75 ft. screw conveyor
- One 14 in. x 200 ft. screw conveyor
- One 14 in. x 400 ft. belt conveyor
- Friction load, motor and shafting, 120 hp. Average load for one ball mill, 28 hp. Average load for one tube mill, 88 hp.

1 75 690 Belted to a 10 ft. shaft and a 50 ft. countershaft—connected load:—
- Two 14 in. x 300 ft. screw conveyors
- One 14 in. x 40 ft. screw conveyor
- Five S. Howes packers
- One elevator

1 10 1120 Belted to a shaft—connected load:—
- One 8x8 ft. cylindrical bag cleaner
- Two sewing machines

LABORATORY

1 ½ 1700 Belted to a Starke No. 112 centrifuge

1 5 1700 Belted to a 10 ft. shaft—connected load:—
- One small grinder
- One small crusher
- One small mixer

REPAIR SHOP

1 15 1120 Belted to a 65 ft. shaft—connected load:—
- One 36 in. hack saw
- One 14 in. cut off saw
- One 12 in. hack saw
- One 20 in. drill
- One 24 in. drill
- One 24 in. engine lathe
- One 20 in. engine lathe
- One 20 in. shaper
- One pipe threader
- One small forge blower

POWER CONSUMPTION—1912

Month	Kw-Hrs.	Bbls. of Clinker Burned	Bbls. of Cement Manufactured	Month	Kw-Hrs.	Bbls. of Clinker Burned	Bbls. of Cement Manufactured
January	49 066	......	.....	July	[illegible]	...	31 586
February	443 733	......	24 [illegible]	August	[illegible]	[illegible]	[illegible]
March	45 866	......	.....	September	[illegible]	[illegible]	[illegible]
April	1 [illegible] 600	66 6[illegible]9	60 4[illegible]	October	1 [illegible]	68 965	[illegible]
May	1 5[illegible] 666	76 167	6[illegible]	November	1 [illegible]	[illegible]	[illegible]
June	754 1[illegible]	......	[illegible]	December	1 [illegible]	[illegible]	[illegible]

PLANT C

This plant has a rated capacity of 2 000 bbls. of cement per 24 hrs. Electrically operated quarries supply the raw material which is brought to the plant by steam power. An average of 200 men are employed working two 10-hr. shifts, 6 days per week.

An aggregate of 2 40[illegible] horse power in induction motors is installed, [illegible] The supply source is three-phase, 550 volts, 60 cycles. The electrical energy consumption per barrel of cement manufactured is 28 kw-hrs.

MOTOR APPLICATIONS

QUARRIES

No.	Hp.	R.P.M.	Type	Application
1	75	850	Squirrel Cage	Belted to a Chicago Pneumatic Tool Co. air compressor to supply air for drills
1	30	1120	Squirrel Cage	Geared to a drum which operates a car haul.

CLAY DRYING AND GRINDING

No.	Hp.	R.P.M.	Type	Application
1	20	1120	Squirrel Cage	Belted to a 15 ft. shaft and a 15 ft. countershaft—connected load:— One set 24x24 in. rolls; One 14 in. x 45 ft. clay elevator; One 6x45 ft. rotary dryer, 9 r.p.m.
1	50	850	Squirrel Cage	Belted to a 5 ft. shaft and 24 ft. countershaft—connected load:— Two 10 in. x 40 ft. screw conveyors; One 14 in. x 35 ft. bucket elevator; One 10 in. x 110 ft. screw conveyor; Two 12 in. x 35 ft. elevators; Two Newago screens

ROCK DRYING AND GRINDING

No.	Hp.	R.P.M.	Type	Application
1	50	850	Squirrel Cage	Belted to a Power Mining & Machinery Co. No. 6 gyratory rock crusher, also one 14 in. x 65 ft. bucket elevator
1	30	1130	Squirrel Cage	Belted to a 12 ft. shaft and a 12 ft. countershaft—connected load:— One 6x45 ft. rotary dryer; One 14 in. x 35 ft. bucket elevator; One 24 in. x 50 ft. horizontal pan conveyor
1	50	850	Squirrel Cage	Each belted to a Williams pulverizer, motor pulley 12x24 in., driven pulley 12x20 in., flywheel on mill 29 in. diam., rim 6 in. x 3½ in.
2	75	860	Squirrel Cage	Each coupled to a short shaft which is geared to a ball mill, 8 ft. diam., 22 r.p.m.

				RAW TUBE MILLS
1	200	550	Squirrel Cage	Belted to a 6½x20 ft. tube mill, 24 r.p.m.
1	150	550	Squirrel Cage	Coupled to a 6½x20 ft. tube mill, 24 r.p.m.
1	125	580	Squirrel Cage	Duplicate of last drive
1	15	550	Squirrel Cage	Belted to a 4 ft. shaft and 6 ft. countershaft—connected load:—
				One 10 in. x 100 ft. screw conveyor
				One 12 in. x 75 ft. bucket elevator
				One 10 in. x 50 ft. screw conveyor
				KILN ROOM
1	20	870	Slip Ring	Belted to a 8x120 ft. kiln 1 1/3 r.p.m.
				Motor also drives one 10 in. x 20 ft. screw conveyor
1	50	850	Squirrel Cage	Belted to a 50 ft. shaft—connected load:—
				Two 8x120 ft. rotary kilns
				Two 10 in. x 20 ft. screw conveyors
				Two 6 in. x 35 ft. bucket elevators
1	75	900	Squirrel Cage	Belted to a Roots size 6½ positive blower, 170 r.p.m.
				FINISH MILL
1	30	850	Squirrel Cage	Belted to a 25 ft. shaft and a 20 ft. countershaft—connected load:—
				One 14 in. x 75 ft. pan conveyor
				One 14 in. x 25 ft. bucket elevator
				One 14 in. x 30 ft. bucket elevator
				One 6x45 ft. rotary dryer, 4 r.p.m.
1	50	850	Squirrel Cage	Belted to a 50 ft. shaft—connected load:—
				Three Newago screens
				One 10 in. x 30 ft. screw conveyor
3	75	860	Squirrel Cage	Each belted to a Sturtevant Mill Co. ring roll mill
4	100	580	Squirrel Cage	Each coupled to a short countershaft and geared to a 6½x20 ft. tube mill, 24 r.p.m.
1	125	575	Squirrel Cage	Duplicate of last drive
1	150	570	Squirrel Cage	Belted to a 6½x20 ft. tube mill, 24 r.p.m.
1	10	1130	Squirrel Cage	Belted to an 8 ft. shaft driving a hopper type grinder for grinding gypsum
1	20	850	Squirrel Cage	Belted to a 10 ft. shaft driving a 14 in. x 25 ft. bucket elevator
1	20	1130	Squirrel Cage	Belted to a 10 ft. shaft, driving one Newago screen
1	20	850	Squirrel Cage	Belted to a 14 in. x 35 ft. bucket elevator
1	30	1120	Squirrel Cage	Belted to a 5 ft. shaft—connected load:—
				One 12 in. x 200 ft. screw conveyor
				One 12 in. x 100 ft. screw conveyor
1	15	1120	Squirrel Cage	Driving a 14 in. x 45 ft. bucket elevator and a 12 in. x 50 ft. screw conveyor
1	15	1120	Squirrel Cage	Belted to a Gates 4-bag sacker, motor pulley 12x10 in., driven pulley 14x16 in.
1	20	1120	Squirrel Cage	Duplicate of last drive
1	50	850	Squirrel Cage	Belted to shafting—connected load:—
				Two 12 in. x 100 ft. screw conveyors
				Two 14 in. x 42 ft. bucket elevators
				One 12 in. x 30 ft. screw conveyor
				One 12 in. x 50 ft. screw conveyor
1	2	1700	Squirrel Cage	Belted to a National sack filling machine
1	10	580	Squirrel Cage	Belted to a 12 ft. shaft driving a two-cylinder horizontal oil pump
1	20	1130	Squirrel Cage	Drives machine shop

POWER CONSUMPTION—1912

Month	Kw-Hrs.	Bbls. of Clinker Burned	Bbls. of Cement Manufactured	Month	Kw-Hrs.	Bbls. of Clinker Burned	Bbls. of Cement Manufactured
January	277 785	12 168	10 076	June	812 645	26 378	37 613
February	502 600	27 825	15 591	July	1 321 530	38 794	67 836
March	963 520	43 310	29 773	August	831 160	23 287	34 326
April	702 840	21 145	30 796	September	720 050	24 482	25 221
May	779 015	21 643	35 782	October	1 112 725	46 153	45 768

Shop Testing of Electrical Apparatus—XIII

ROTARY CONVERTERS

THE rotary converter has the same general structure as a direct-current generator, with the addition of taps from the armature winding to the slip rings, and the same preliminary examinations of bearings, armature, commutator and connections should be made. The settings of the brushes and brush-holders, the polarity of the field coils, and the adjustment of the commutating field strength* should be checked carefully.

The data obtained from tests taken on a standard 500 kilowatt, 60 cycle, six-phase, eight-pole, 600 volt rotary converter will be used throughout this article to illustrate the various tests described and the determination of the performance from the results obtained.

RESISTANCES.

The resistances for the armature and series field were measured with the Kelvin double bridge. The resistance of the shunt field was measured by the Wheatstone bridge and was also taken by the voltammeter method. This latter reading is used in connection with the last reading of the voltage drop across the field at the end of any temperature test to determine the rise in temperature of the shunt windings during the test, as the bridge reading which is taken after shut-down, should show a slightly lower resistance and, therefore, not the maximum temperature that existed at the end of the test. The resistances as measured are given in Table I. For calculating the rise in temperature of the rotating copper, it is frequently more convenient to measure the voltage drop across the slip rings, using the same rings for both cold and hot resistances. The rings of a rotary converter are usually numbered from the winding outwards; and in order to make practice uniform and to obtain the maximum value, the resistance should be taken between rings *1* and *3*, of two and three-phase machines, and between rings *1* and *4* of six-phase machines.

Since the heating in the armature copper is due to the difference between the alternating and direct current in the coils, the copper loss cannot be calculated on the same basis as that of either a direct or an

*See the JOURNAL for April, '13, p. 370.

alternating-current machine. The equivalent heating effect, however, can be determined by means of a percentage factor, which will be referred to as *K*, and may be defined as the ratio of the heating in the armature of a converter operating as such, to the heating in the same machine operating as a direct-current generator at the same output. A number of curves are plotted in Fig. 2 showing this ratio for the average heating and also the heating at the tap coils of rotary converters for different power-factors.* Assuming three percent rotational losses, the percentage factor *K* for the average heating in the armature is given in Table II, for power-factors at the limits of the curves of Fig. 1.

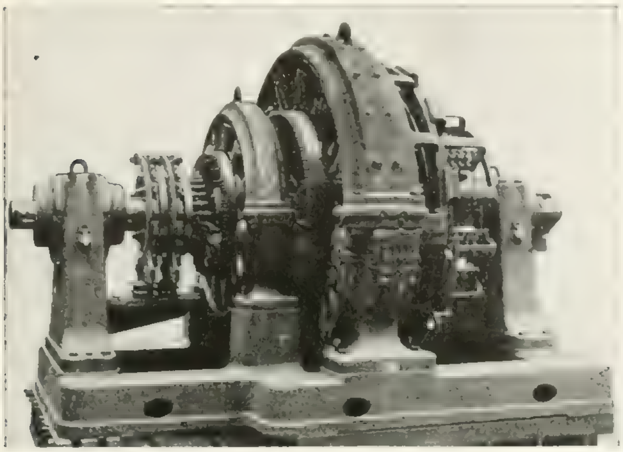


FIG. 1—A 2000 KILOWATT, 600 VOLT, 60 CYCLE, COMMUTATING-POLE ROTARY CONVERTER

Temporarily set up for an engineering test.

PRELIMINARY INSPECTION

The rotary converter is belted to a direct-current motor of sufficient capacity to run the machine with losses up to 20 percent over-voltage, and a thorough mechanical inspection made. The machines are then started slowly, observing that all parts revolve freely and that the oil rings are turning properly.

TABLE I—RESISTANCES

Winding	Ohms at 22.5 degrees C.*	Ohms at 25 degrees C.
Armature Between Brushes	0.01239	0.0125
Armature Between Rings, 1-4	0.01287	0.0130
Series Field	0.001264	0.001277
Shunt Field (Bridge)	76.00	76.60
Shunt Field (Volt-ammeter)	75.65	76.27

*Room Temperature 22.5 Degrees C.

The brushes of the converter should be set on the approximate neutral, and the field so excited as to give 20 percent over-voltage at the terminals of the machine. The excitation is gradually increased, watching continually for signs of short-circuited coils or commutator bars, and the over-voltage is held on the machine several minutes to give even slight defects time enough to show up. The converter should then be run on short-circuit to season the commutator.* In cases where the mica has been undercut, the final depth after grinding must be not less than one-sixteenth of an inch from the surface of the commutator.

*See the JOURNAL for Sept., 1913, p. 882.

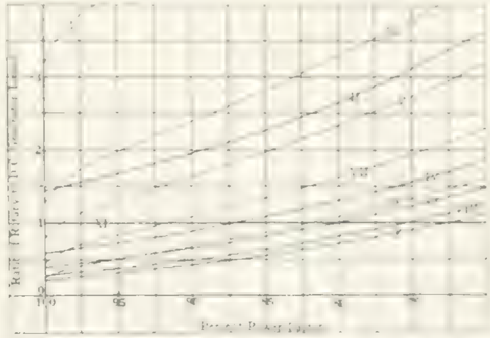


FIG. 2—HEATING OF THE ARMATURE OF A ROTARY CONVERTER OPERATING AS SUCH, COMPARED WITH ITS HEATING WHEN OPERATING AS A DIRECT-CURRENT GENERATOR

Solid lines represent average heating and dotted lines that of the tap coils.

I—2 rings	V—4 rings	IX—12 rings
II—2 rings	VI—4 rings	X—12 rings
III—3 rings	VII—6 rings	XI—Direct Current
IV—3 rings	VIII—6 rings	

VOLTAGE RATIOS

In order to determine whether the various taps are connected properly, readings of voltages between rings are taken, while the voltage on the direct-current side is held constant. The voltage between phases should balance up exactly; on a two-phase machine the phases should be across rings 1-3 and 2-4; on a six-phase machine, if diametrically connected, the phases should be across rings 1-4, 2-5 and 3-6, and if double delta connected, one delta should be on rings 1-3-5 and the other on rings 2-4-6.

TABLE II—K FOR AVERAGE ARMATURE HEATING

No. of Rings	K at 70.7 Percent Power-Factor	K at 100 Percent Power-Factor	Percent Power-Factor at which K = Unity
1 Phase, 2 Rings	3.051	1.45	......
3 Phase, 3 Rings	1.847	0.587	87.0
2 Phase, 4 Rings	1.452	0.389	80.0
6 Phase, 6 Rings	1.201	0.274	75.5
12 Phase, 12 Rings	1.087	0.2069	72.5

The ratios of alternating to direct voltage for converters of the number of phases indicated are given in Table III. These ratios are determined by the formula,

$$\text{Alternating e.m.f.} = \frac{\text{direct e.m.f.}}{1.415} \sin. \frac{180^\circ}{N}$$

where N = the number of rings of the converter. The ratios as actually read may differ slightly from

*See the JOURNAL for April, 1913, p. 371.

those given in Table III, depending on variations in wave form for different machines. A complete set of voltage readings is given in Table IV, with 600 volts on the direct current side. These values

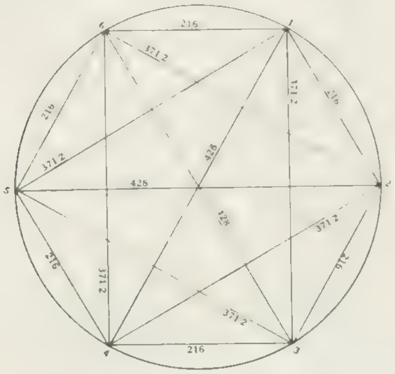


FIG. 3—GRAPHIC REPRESENTATION OF VOLTAGES BETWEEN EACH PAIR OF RINGS OF A SIX-PHASE ROTARY CONVERTER

may be more clearly appreciated if considered in connection with such a diagram as Fig. 3.

STARTING TESTS

Rotary converters are started by one of three methods:—

By a Small Induction Motor—The starting motor has one pair of poles less than the converter and must have sufficient starting torque to start the machine from rest. The motors are of the constant speed type with such a slip that the no-load losses of the converter will be sufficient to load the starting motor to the point where it will drive the converter at approximately synchronous speed.

TABLE III—VOLTAGE RATIOS—DIRECT VOLTAGE UNITY

No. of Phases	1	3	2	6 Diametrical	6 Double Delta
No. of Rings	2	3	4	6	6
Voltage between Successive Rings	0.707	0.612	0.50	0.353	0.353
Phase Voltage	0.707	0.612	0.707	0.707	0.612

TABLE IV—VOLTAGE READINGS

Between Rings	Voltage	Between Rings	Voltage	Between Rings	Voltage
1-2	216	2-3	216	3-5	371.2
1-3	371.2	2-4	371.2	3-6	428
1-4	428	2-5	428	4-5	216
1-5	371.2	2-6	371.2	4-6	371.2
1-6	216	3-4	216	5-6	216

In testing a starting motor the connections as given in Fig. 4 should first be checked carefully and the line switches for the motor then closed. The line voltage is increased gradually until the converter starts, readings being taken of starting volts and amperes at the point of starting, this procedure being repeated several times as a check. The outfit should then be allowed to come up to speed and the field put on the converter to give normal voltage; this should bring it approximately into synchronism. If it does not, any convenient load, such as a small direct-current load, should be added until synchronous speed is

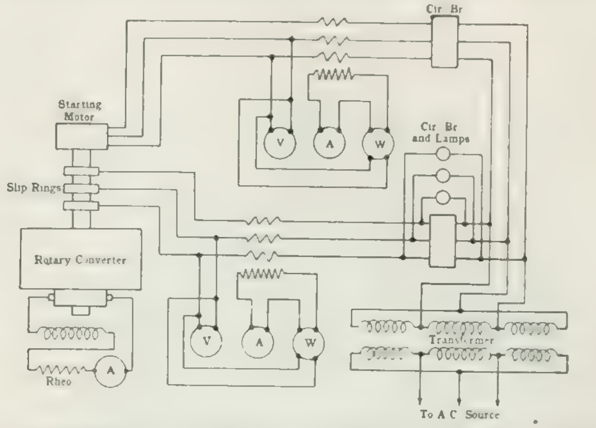


FIG. 4—METHOD OF CONNECTION USED IN TESTING A ROTARY CONVERTER STARTING MOTOR

obtained and note made of the additional load required. The minimum starting motor voltage at which the converter can be synchronized should also be found. With the outfit at synchronism, a reading of watts, amperes and volts on the driving motor should be made.

As an Induction Motor, with Auto-Transformers—Converters started according to this method are termed self-starting. The starting tests are taken in the same manner as outlined under starting tests on synchronous motors. The field may be short-circuited on itself, or may be left open, but must not be excited, as this will cause destructive flashing at the brushes. If left open, the field circuit must be sec-

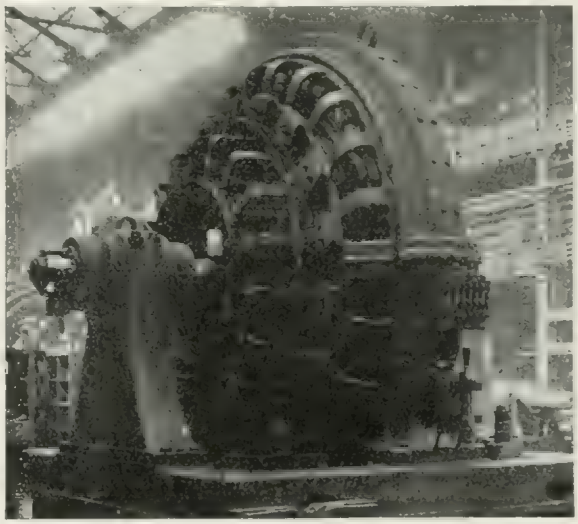


FIG. 5—A 1000 KILOWATT, 270 VOLT, 60 CYCLE, COMMUTATING-POLE SYNCHRONOUS BOOSTER ROTARY CONVERTER
Completely assembled and ready for test.

tionalized by a double-pole field break-up switch, to prevent the generation of an excessive voltage. This switch also serves as a reversing switch, as the converter may build up its voltage in a direction contrary to normal. As soon as the converter has reached synchronous speed, the field switch should be closed

and the polarity of the voltage noted; if incorrect, the switch is thrown to the other side.

In compound converters, a series shunt disconnecting switch is also mounted on the frame. This should be left open* in starting, otherwise a circulating current between the series field and the German silver shunt will be set up which reacts on the armature, reducing the starting torque and causing at times vicious flashing at the commutator.

Commutating-pole converters of large capacity are equipped with a brush-lifting device by means of which all the brushes, except those on two brush arms, are raised when starting. These brushes merely furnish the voltage necessary to excite the shunt field, so that the machine can be synchronized. If all the brushes are down when synchronizing, severe flashing occurs, due to the reduction in the reluctance of the rotating field magnetic path by the steel in the commutating poles, which causes a higher e.m.f. to be induced in the armature coils than would be the case in non-

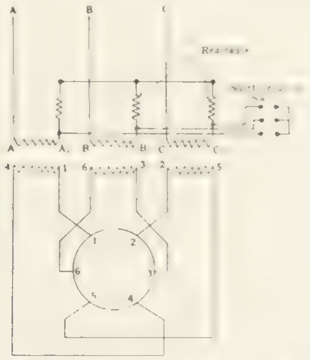


FIG. 6—METHOD OF STARTING A ROTARY CONVERTER FROM A NORMAL VOLTAGE SOURCE BY MEANS OF REACTANCE

commutating-pole machines. In starting converters by this means the voltage is applied and slowly increased until the machine just starts. This is repeated several times, readings being taken of starting volts and amperes. The converter is then allowed to increase in speed and the voltage required to bring it to synchronism should be noted.

Starting at Normal Voltage with a Reactance—For this method the connections are as shown in Fig. 6. When starting, the reactance short-circuiting switch and the field break-up switch are left open. The line switch is then closed and upon reaching synchronous speed the field switch is closed and the direct-current brushes are dropped, if the polarity is correct. The switch short-circuiting the reactance is then closed.

In this test readings of primary transformer voltage, secondary voltage and voltage across the reactance should be taken at the moment of starting. Any abnormal conditions when throwing in the short-circuiting switch, such as rush of current, flashing at the brushes, etc., should be noted.

Starting from the Direct-Current End—The machine is started as a shunt motor and then synchronized with the line. The series field circuit must be open and a starting resistance used with this manner of starting.

CORE LOSS AND SATURATION

These tests are identical with those explained for direct-current motors.* The converter may be driven by a separate shunt motor or it may be operated as a shunt motor. The data given herewith was obtained by the former method. Readings from zero to 125 percent normal voltage are taken of volts, amperes and field current on the driving motor and speed, field current and volts, both alternating and direct, on the converter The increase in driving-motor current at any point over the value at zero field current on the converter is that due to the core loss at that point. This difference multiplied by the motor voltage therefore equals the core loss in watts.

It is frequently the case that a non-adjustable direct-current source or an adjustable source of insufficient voltage is used to excite the converter field and therefore the excitation is limited. Where higher voltages are desired, the converter may be self-exciting. The last four points in this test were taken in this manner, as indicated in Table V. Accordingly the loss measured is in excess of the core loss by an amount equal to the copper loss in the field. The proper correction is made by subtracting from the total, the product of the converter volts and its field amperes.

The brush friction is determined by finding the difference in driving motor input with brushes down and brushes up. A check reading is taken with normal field and brushes up on the converter. The difference in driving motor input without field and with field, the brushes being up, will equal the core loss and should check the corresponding point with brushes down if there are no circulating currents in the short-circuited coils under the brushes.

The friction and windage loss equals the decrease in driving motor input with the brushes up on the converter and with the belt off. Complete readings together with the resultant data are given in Table V. The core loss and voltage saturation curves are given in Fig. 7.

ALTERNATING-CURRENT SATURATION

The short-circuit test is taken to obtain the synchronous impedance with the armature short-circuited on the alternating-current side, and can only be made with a separate driving motor. The armature is short-circuited through series transformers, so arranged that the current in each phase may be read. The brushes should be down on the direct-current end.

*In some of the more recent types of converter, it is possible to short-circuit the shunt field on itself and to leave the shunt closed on the series field. This in many machines produces severe sparking at the brushes. Hence before attempting to start a converter in this way, the operator should determine if the design of the machine will permit this method. Where it is possible, the shunt field may be short-circuited at the switchboard, and no attendance at the machine is necessary.

*See the JOURNAL for April, 1913, p. 379.

The test is taken in the same manner as on an alternating-current generator,* with the exception that the input to the driving motor is not read. The readings for this test are given in Table VI and the corresponding curve in Fig. 7. The locked saturation test for a rotary converter is taken in the same manner as for synchronous motors.*

VOLTAGE CONTROL

The voltage regulation on rotary converters can only be correctly obtained when the entire equipment of transformers and reactance is tested with the machine. The adjustment generally required is that of constant terminal voltage from no-load to full-load on the direct-current side. As the value of the terminal voltage for any given load and power-factor is dependent on the value of the alternating voltage applied to the slip rings, any change in the former must be accomplished by changing the latter; this can be accomplished by adjusting the shunt field for each change in load, or using a compound-wound machine in connection with the reactance of the line and transformer, using reactance coils to supply the same effect when running directly from a generator; by the use of a potential regulator to vary the alternating-current voltage; or by using an alternating-current booster on the same shaft as the converter armature and connected in series with the alternating-current lines.

A compound-wound converter operating with reactance may be compounded in the same manner as a direct-current generator. Unless otherwise specified the supply voltage should be held constant and the converter shunt field adjusted to give the correct voltage at no load; then with this same adjustment full load is put on the machine. If it over-compounds, the series field is too strong and gives too large a leading current in the feeder lines,* in which case a shunt must be adjusted across the series winding. In this compounding test all readings are taken and all adjustments made without changing the field rheostats after the no-load adjustment is obtained.

TABLE V—CORE LOSS AND SATURATION DATA

	Driving Motor					Rotary Converter			
	Line Volts	Field Amps.	Line Amps.	Change in Amperes	Watts Core Loss= Change in Amperes Times Volts (110)	R. P. M.	Direct Voltage	Alternating Voltage	Field Current
(1)	110	5.98	112	....	......	904	10	....	0
(2)	110		115	(2)—(1)= 3	330	902	100	64	0.70
(3)	110		121	(3)—(1)= 9	990	901	200	140	1.38
(4)	110		130	(4)—(1)=18	1980	896	300	212	2.05
(5)	110	5.90	142	(5)—(1)=30	3300	900	400	284	2.88
(6)	110		156	(6)—(1)=44	4840	902	500	356	3.8
(7)	110		165	(7)—(1)=53	5830	900	550	393.6	4.4
(8)	110		176	(8)—(1)=64	7040	900	600	428	5.1
(9)	110		189	(9)—(1)=77	8470	901	650	461.2	5.9
Converter Self-Excited—Armature in Series with 500 Volt Line.									
(10)	110	5.85	235	(10)—(1)=123	13520—4370*= 9150	901	675	478	6.48
(11)	110		250	(11)—(1)=138	15180—4970*=10219	902	700	494	7.1
(12)	110	5.75	264	(12)—(1)=152	16720—5620*=11100	903	725	510	7.75
(13)	110		279	(13)—(1)=167	18390—6380*=12010	902	750	527	8.5
(1)	110	5.98	112	Check on (1)		899	10	.....	0
Commutator Cleaned and Oiled.									
14	110	5.98	108			899	10	......	0
All Direct-Current Brushes Up—No Field.									
15	110	5.98	100	(14)—(15)= 8	Brush Friction 880	902	0	0	0
All Direct-Current Brushes Up with Field.									
16	110	5.90	163			901	0	0	5.1
Belt Off.									
17	110	5.98	10	(15)—(17)=90	Friction and Windage 9900	......	......	.....	......

*These readings were taken with the converter self-excited and the field losses are subtracted accordingly in calculating the core loss.

METHODS OF LOADING

A rotary converter can be loaded by either of two methods:—

Actual Power Load—In this method the machine

*See the JOURNAL for Nov., 1913.

*See article on "Voltage Regulation of Compound Rotary Converters" by Jens Bache-Wiig, in the JOURNAL for Nov., '10, p. 860.

is operated as a standard or as an inverted rotary converter in accordance with the manner in which it will run in service and the source of power must have sufficient capacity to supply the entire load and overload of the converter. When running from alternating to direct current, the alternating voltage is adjusted to obtain the normal voltage in the direct-current side at no load and the shunt field then adjusted to give the minimum armature current. When running the machine from direct to alternating current, normal voltage is held on the direct-current side and the shunt field is adjusted to give the rated speed.

TABLE VI—ALTERNATING-CURRENT—
SHORT-CIRCUIT SATURATION

Short-Circuit Amperes	138	200	277	415	554
Field Current	0.78	1.17	1.65	2.46	3.28

Loading Back Method—The losses in this method can be supplied for both machines from either the direct or the alternating-current side or both as may be desired. The connections between the machines may consist of complete metallic circuits or the alternating-current sides may be connected together through transformers. In the former method, circulating current is provided by an induction regulator in the alternating-current side, and a careful adjustment of resistance is necessary in the direct-current lines to avoid a circulation of current through one side of the circuit, via the alternating leads, which does not pass through the meters in the other direct-current lines. To avoid this possibility, it is desirable to connect transformers of a 1:1 ratio in the alternating-current lines. The load may then be provided by induction regulators, or by a booster in the direct-current lines, as shown in Fig. 8. This latter method is the one usually preferred, on account of the ease with which the load can be controlled, the more stable conditions, and the entire absence of any circulating currents which would not be indicated by the direct-current meters

FIG. 7—CURVES SHOWING NO-LOAD SATURATION, BOTH DIRECT AND ALTERNATING-CURRENT, SHORT-CIRCUIT ALTERNATING-CURRENT SATURATION AND CORE-LOSS

The losses in this test are usually supplied partly from the direct-current side and partly from the alternating-current side, the speed and alternating-current voltage being controlled from the alternating-current power supply, and the load being controlled by a booster in the direct-current line. When the machines are compound wound it is necessary to reverse the series field of the machine running as an inverted converter.

The machines are connected as in Fig. 8, with the brushes set on the no-load neutral. Then, after a careful check on all wiring and connections, the machines are brought up to speed, the frequency and voltage are adjusted to their respective rated values and the shunt field excitation is adjusted for the minimum armature current input. When the machines are ready to be paralleled on the direct-current side, the booster field circuit should first be closed and voltage readings taken to determine that the booster is increasing the voltage to the machine that is run as an inverted rotary converter, so that after the machines are paralleled, the current will circulate in the proper direction; the voltage output of the standard converter being considerably lower than the voltage input to the inverted converter. The field circuit on the booster should then be opened.

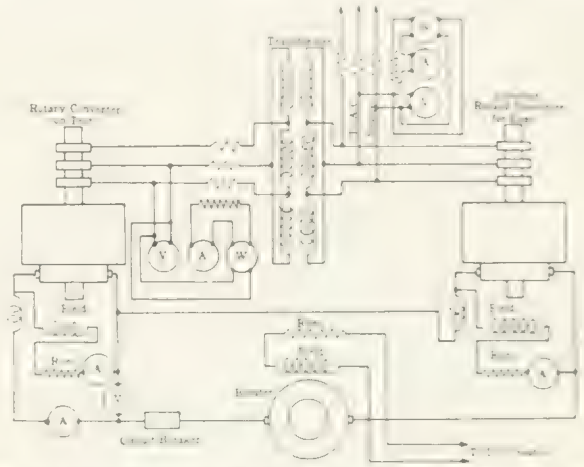


FIG. 8—DIAGRAM OF CONNECTIONS FOR LOADING A ROTARY CONVERTER BY THE LOADING BACK METHOD

The negative sides of the two machines being connected directly together and the positive sides open, the voltage on each machine should be carefully checked between the negative line and the jaws of the paralleling switch; the voltage across the standard machine should be slightly higher than that on the inverted machine. The paralleling switch and the booster field switch are then closed and the booster field gradually increased until the desired load current is flowing between the two machines.

When starting, the standard converter voltage is higher than that of the inverted machine, but when loaded the reverse is true. The brushes should be set on the full-load neutral position, this being the same

as the no-load position on commutating-pole converters, but a slight lead being required on non-commutating-pole machines, operating normally.

A reading is taken of the input to the alternating-current side of the standard machine and the shunt-field excitation is then varied up and down, maintaining the output constant, to determine whether the input current is the minimum for that load. If the minimum current is obtained with a different shunt-field current than that required at no-load the adjustment of series field strength is incorrect.

Loading on Another Line—With this method of loading, it is generally advisable on the test floor, to use a booster on the direct-current side to regulate the load. The connections for such a test are shown in Fig. 9. With the direct-current circuit open the shunt-field current is adjusted for minimum armature current at no load. The machine is then paralleled

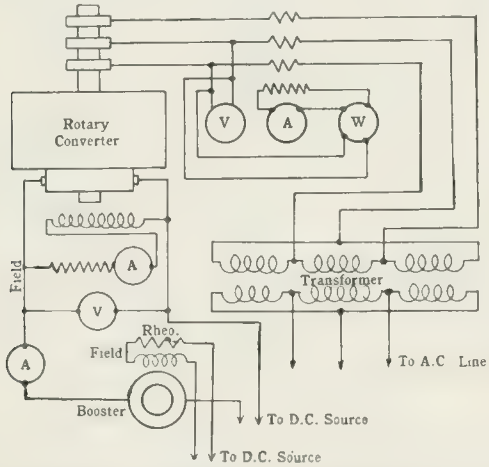


FIG. 9—CONNECTION DIAGRAM FOR STARTING A ROTARY CONVERTER FROM THE DIRECT-CURRENT END

with the direct-current power circuit and the test conducted in the same manner as when using a similar machine for load.

INVERTED ROTARY CONVERTERS

The speed of the standard converter is controlled entirely by the frequency of the circuit from which it is operating, while the inverted rotary converter is similar to a direct-current motor in that the speed is controlled by the field strength entirely. Because of this the frequency of the alternating-current will vary over the different values of load, more particularly if the machine is compound wound, and, moreover, as the field strength is reduced by the presence of a lagging current in the alternating-current load, an inductive load will produce very unstable conditions in the converter and may even weaken the field to an extent which will cause the armature to acquire a dangerous speed It is for such cases that over-speed devices are installed on converters to trip the circuit breakers in the direct-current circuits, should the speed exceed the safe value for which they are adjusted.

In most cases where rotary converters are used inverted, they are equipped with a separate exciter direct-connected to the converter shaft. The exciter is designed to operate normally quite low on its saturation curve so that when the converter speed increases the exciter voltage increases in greater proportion, thus increasing the converter excitation and tending to keep the speed normal.

Inverted converters are operated with series fields almost, if not entirely, short-circuited. The tests are the same as for standard converters with the additional precaution of using over-speed devices.

SYNCHRONOUS BOOSTER ROTARY CONVERTERS

In this type of machine the armature of a low-voltage, alternating-current generator is mounted on the same shaft as the converter and the various phases from the converter are connected through this armature to the collector rings, so that the voltage impressed on the converter may be increased or decreased at will by adjusting the booster field. The field yoke of the alternating-current generator is made

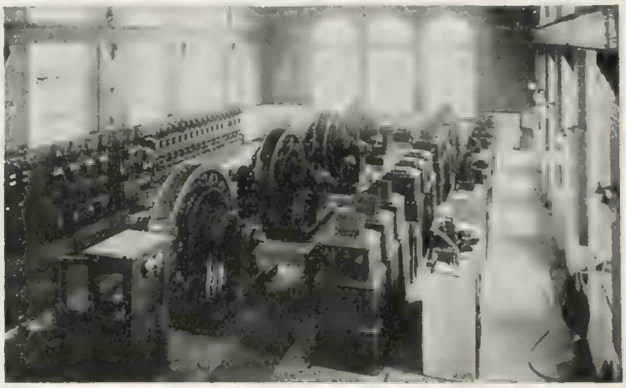


FIG. 10—A TYPICAL INSTALLATION OF 1 500 KW. 60 CYCLE ROTARY CONVERTERS, DIRECT VOLTAGE 600, WITH ACCOMPANYING TRANSFORMERS AND SWITCHBOARDS

adjustable so that the field can be moved around to obtain the proper phase relation in the two armatures.

To obtain the proper phase relation between the converter and its booster generator, the fields of both machines must be excited to give their respective normal voltages as shown by the no-load saturation curves. The voltage on the direct-current side of the converter should be held constant at its normal value and readings taken of the voltage between phases with no field on the booster, and with the normal booster field increasing and also decreasing the voltage between phases. When the voltage between phases shows the same value of increase or decrease from the normal voltage between phases with the same field on the booster in either direction, the field yoke of the booster is properly adjusted, but if the amount of increase and decrease is different the phase relation of the two machines is not correct and the field yoke of the booster, which is usually adjustable, must be moved around slightly. The field circuit of both converter and booster must be opened when making any adjustment of the booster field yoke.

The mechanical inspection and electrical tests for this type of converter are the same as those outlined for the standard machine. On the alternating-current

booster, the core loss and saturation are the only tests taken on the machine as a separate unit. This test must necessarily be made by the separate driving motor method. To obtain the saturation curve of the booster it is absolutely necessary that the residual magnetism be removed from the field of the converter as this will increase or decrease the voltage obtained on the booster saturation test. This can be done by flashing the shunt field of the converter with a low current until the voltmeter on the direct-current side of the machine shows no deflection. These tests should be taken on the booster in both directions, and should check very closely with each other.

TEMPERATURE TESTS

Temperature tests are made to determine the maximum temperature of each part of the machine and also to note the commutation and general mechanical operation of the machine. The continuous temperature run at normal load should be continued for at least one hour after all parts have reached an apparently constant temperature.

To determine when the temperatures have become constant, readings of thermometers placed on the field coils may be taken, as this part of the machine is the last to attain a constant temperature. However, readings of shunt and series field drops are a better indication of this condition.

Overload runs are usually started when the machine is at full-load temperature. The machine should first be heated up on full-load until constant and then the load changed to the required overload as quickly as possible. The run should be ended exactly at the end of the required time, as a difference of a few minutes will sometimes affect the temperatures materially.

For both runs, readings are taken of line volts and line amperes on both alternating and direct-current ends, shunt field amperes and volts, series field amperes and series field potential drop. A check on the power-factor to see that it remains at 100 percent during the test is taken at intervals by wattmeter readings on the alternating-current end. The commutator condition should be noted before and after the test as well as the commutation during the test.

Rotary converters are usually equipped with mechanical oscillators and during the test this should be adjusted to give the required end play. In operation, rotary converters are frequently oiled at the commutators, but as a test run, this should not be done if satisfactory operation can be obtained without it. If it is necessary, however, it should be done at intervals of not less than two hours and the fact should be noted in working up the test results.

In taking a heat run, a no-load reading should be taken at normal no-load conditions and the shunt field adjusted for minimum armature current, noting as to whether the field current checks the reading at the same voltage in the no-load saturation test. If necessary, a shunt is adjusted on the series field to give minimum current on the alternating-current end, holding the shunt-field current at the same value as at no load. On continuous runs, readings should be taken every hour, and on overload runs, every half hour, the load and voltage being maintained constant.

When the temperatures have become constant, the power supply circuit is opened and the machine allowed to come to rest, under load if possible, noting the method and length of time of shut-down. Temperatures by thermometer are then taken on the commutator, armature iron, armature copper, armature copper at tap coils, series field, commutating field, bearings, collector rings and shunt field. Hot resistance should be taken as soon as possible after shutdown in the following order:—Series field without shunt; commutating field without shunt; armature, across rings, and shunt field.

*See the JOURNAL for Jan., 1913.

EFFICIENCY BY LOSSES

The determination of the efficiency of rotary converters is effected by calculation of losses from the results of other tests. The values of core loss, brush friction, friction and windage, resistance and temperature data are used in this test to determine the losses at no load and each quarter load up to 25 percent overload. Efficiency is then determined from the following relations:—

Let E = Rated direct terminal volts.
I_t = Terminal amperes.
I_s = Shunt field amperes at load I_t.
I = Total armature amperes $I_t + I_s$.
r = Armature resistance hot or at 60 degrees C.
r_e = Equivalent armature resistance $r \times k$.
(For value of "k," see table I.)
r_1 = Series field resistance hot or at 60 degrees C.
r_2 = Shunt on series field.
r_3 = Resistance of series field with shunt $= \frac{r_1 \times r_2}{r_1 + r_2}$
r_4 = Commutating field resistance hot or at 60 degrees C.
r_5 = Resistance of shunt on commutating field.*
r_6 = resistance of commutating field with shunt $= \frac{r_4 \times r_5}{r_4 + r_5}$.
B = Volts brush drop $= \frac{\text{Direct current [illegible]}}{20 \times \text{Total brush area}}$ [illegible]
R = Armature equivalent resistance (r_e) + series field resistance (r_1 or r_3) + commutating field resistance (r_4 or r_6).

The above formula for R must include the running resistance of all windings in series with the armature.

$e = I \times R$ (Total drop of all series windings).
(1) Total induced volts $= E + e + B$.
(2) Core loss at total induced voltage (1) (from core loss curve).
(3) Shunt field copper loss $= E \times I_s$.
(This will include the rheostat in the shunt field.)
(4) Copper loss of armature and windings in series with it, I^2R.
(5) Brush I^2r loss $= I \times B$.
(6) Brush friction + friction and windage.
(Alternating-current brush friction is included in the friction and windage.)
Total losses = (2) + (3) + (4) + (5) + (6).
Output $= E \times I_t$
Input = Output + total losses.
Efficiency $= \frac{\text{Output}}{\text{Input}}$.

*A shunt on the commutating field is of very infrequent occurrance on rotary converters.

EFFICIENCY OF SYNCHRONOUS BOOSTER CONVERTERS

In determining the efficiency of a synchronous booster rotary converter, there are some additional losses which were not mentioned in the above discussion. These are the booster field copper loss, the commutating-pole auxiliary field copper loss, the booster armature copper loss and the booster core loss. The copper loss of the booster armature and armature copper loss of the rotary converter itself vary considerably for a constant direct-current output, depending upon the actual amount of boost. When the boost is positive, the booster is raising the direct-current voltage. It is then acting as a generator, being driven mechanically by the converter acting as a synchronous motor. When the boost is negative the booster is lowering the direct-current voltage; it is then acting as a synchronous motor delivering power mechanically to the converter. The converter, therefore, under this condition delivers some of this output as a direct-current generator. In the first case the additional current flowing in the armature of the converter is an alternating current, in the second case a direct current. In either case the current is proportional to the percent boost and in each case it may be considered to be a direct current in order to make the calculation simpler.

Taking these additional factors into consideration, the relations used in the determination of efficiency are as follows:—

K = Ratio of rotary converter armature copper loss to same as a direct-current generator. See Fig. 1.

E = Direct terminal voltage.

I_t = Direct terminal amperes.

I_s = Shunt field amperes.

I_b = Synchronous booster field amperes.

I_a = Rotary converter commutating-pole auxiliary field amperes.

$I_b = I_a$ since the two fields are in series.

$I = I_t + I_s + I_b$ = armature output current.

I_1 = Alternating-current per collector ring at normal voltage.*

r = Rotary converter armature resistance at 60 degrees C.

r_1 = Resistance at 60 degrees C. of one booster armature winding between collector ring and armature tap.

r_2 = Resistance of main commutating field.

P = Pairs of poles on rotary converter or booster.

N = Number of phases or collector rings.

X = Percent boost (the sign of X may be plus or minus).

(1) $(1+X)\, I_1^2 \, \frac{r_1 N}{P}$ = Booster armature copper loss under all conditions.

(2) KI^2r = Rotary converter armature copper loss—no boost.

$KI^2r + r\left(\left[(1+X)\, I\right]^2 - I^2\right)$ = Rotary converter armature copper loss—positive boost.

$Kr\left[(I+X)\, I\right]^2 + r\left[I^2 - \left[(1+X)\, I\right]^2\right]$ = Rotary converter armature copper loss—negative boost.

(3) EI_b = Copper loss in booster field and auxiliary commutating field.

(4) EI_s = Copper loss in shunt field.

(5) I^2r_2 = Copper loss in main commutating field.

(6) = Brush I^2r loss.

(7) = Core loss of converter at total induced volts.

(8) = Core loss of synchronous booster at number of volts boost (positive or negative).

(9) = Brush friction.

(10) = Bearing friction and windage.

Total losses = (1) + (2) + (3) + (4) + (5) + (6) + (7) + (8) + (9) + (10).

Total Input = Output + total losses.

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

A complete calculation of efficiency for the machine used in connection with the tests already described is given in Table VII.

COMMUTATING-POLE SATURATION

This test is made in the same manner as for direct-current generators. On booster converters the commutating-pole saturation is taken at both positive and negative boost as well as the mean position. Each saturation should be taken for the same voltage on the alternating-current side.

TABLE VII—CALCULATIONS FOR EFFICIENCY

Resistance at	25 Degrees C.	At 60 Degrees C.
Armature	0.0125	0.0142
Series Field	0.001277	0.00145
Series Field with Shunt	....	0.0004425
Shunt Field	76.27	86.5

Total Brush Area—42 Square Inches.

Load, Percent	0.25	0.50	0.75	100.	125.	150.
Line Amperes	208.3	416.7	625.	833.	1042.	1250.
Shunt Field Amperes	4.9	4.9	4.9	4.9	4.9	4.9
Armature Amperes	213.2	421.6	629.9	837.9	1046.9	1254.9
Terminal Volts	600.	600.	600.	600.	600.	600.
Armature Drop	0.8	1.62	2.42	3.26	4.07	4.88
Series Field Drop	0.09	0.19	0.28	0.37	0.46	0.56
Brush Drop	1.25	1.5	1.74	1.99	2.24	2.49
Total Induced Volts	602.2	603.3	604.4	605.6	606.7	607.9
Core Loss	7.05	7.07	7.09	7.12	7.15	7.18
Armature, I^2R. Loss	0.18	0.69	1.51	2.73	4.25	6.12
Series Field Loss	0.02	0.08	0.18	0.31	0.48	0.70
Shunt Field Loss	2.94	2.94	2.94	2.94	2.94	2.94
Brush Loss	0.27	0.63	1.09	1.67	2.34	3.12
Brush Friction	0.88	0.88	0.88	0.88	0.88	0.88
Friction and Windage	9.9	9.9	9.9	9.9	9.9	9.9
Total Losses	21.24	22.19	23.59	25.55	27.94	30.84
Kilowatt Output	125.	250.	375.	500.	625.	750.
Kilowat Input	146.2	272.2	298.6	525.6	652.9	780.8
Efficiency	85.5	91.8	94.1	95.1	95.9	96.1

COMMERCIAL TESTS

This type of test is used only where apparatus is manufactured and tested on a large scale and is not applicable to determining the performance of an individual machine. In the case of rotary converters, only such tests are necessary as will detect any mechanical or electrical defects and determine the similarity of the machine to the standard design on which a complete engineering test has been run.

The following tests are sufficient for the above purposes on standard lines of apparatus:—

1—Seasoning and grinding the commutator.
2—Neutral check.
3—Polarity test.
4—Core loss and direct and alternating-current saturation.
5—A temperature test of sufficient duration to check its similarity to that of the standard machine.
6—Cold and hot resistances.

These tests have already been described in detail and constitute a very complete commercial test. Where apparatus has been built in such large quantities as to be very familiar to tester and engineer, an even shorter test is taken, consisting of the above tests without the temperature run. A mechanical inpection and insulation test completes the test.

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*If B = percent efficiency of which a first approximation must be made;

C = ratio of al ternating to direct voltage at normal voltage operation;

$I_1 = \frac{I}{2\,BC}$ for two-phase converters.

$I_1 = \frac{I}{1.73\,BC}$ for three-phase converters.

$I_1 = \frac{I}{3\,BC}$ for six-phase converters.

*See the JOURNAL for June, 1913.

Armature Reaction

IN DIRECT-CURRENT MACHINES

R. H. Taber

THE DIRECT-CURRENT generator or motor consists essentially of two interrelated electrical circuits; viz., the field and armature windings. When carrying current, each of these electrical circuits sets up a magnetic field, and the change in density and distribution of the main field caused by the armature field is termed the armature reaction. .

PRINCIPLE OF ACTION.

The principle of armature reaction may be represented graphically, as shown in Fig. 1. Current flow-

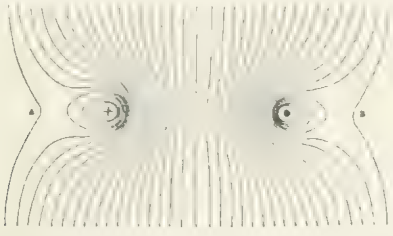

FIG. 1—THE EFFECT OF CURRENT-CARRYING CONDUCTORS ON A UNIFORM FIELD

ing in a conductor sets up a local magnetic field surrounding it. If the conductor is located in an already existing and uniform field of force, a resultant field is formed, stronger at one side of the conductor where the forces add, and weaker on the other side, where the action is opposed. If, in place of a single conductor, a belt of conductors carrying current in the same direction lies in such a field, similar action takes place, but the resultant distortion of the main field is greatly

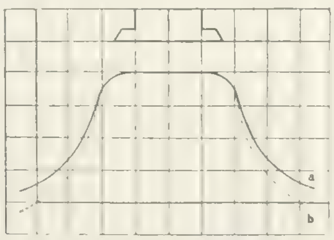

FIG. 2—NO-LOAD FIELD FORM

a—Due to a single pole. b—The same with effect of adjacent poles. The ordinates of the field form represent the magnetic flux densities in the air-gap, and on the assumption of constant magnetomotive-force, may be plotted with reasonable accuracy as inversely proportional to the length of flux paths between armature and pole face, except in the neutral zone, where the field form is modified to pass through zero, due to the action of adjacent poles of opposite polarity.

increased. This is the condition which exists in the direct current machine.

DISTORTION OF MAIN FIELD

The field winding may be considered as supplying a magnetic field of force, the general shape of which is indicated by the field form or flux density diagram, Fig. 2. At no load there is a uniform flux distribution in the air-gap beneath the poles as shown in Fig. 3.

The armature winding may be considered as if externally excited but carrying current flowing in the same direction as in operation and setting up a corresponding magnetic field, as represented in Fig. 4.

Combining the two magnetic fields gives a resultant magnetic distribution, Fig. 5, in which the direction of the main flux is shifted from the center of the poles towards the tips, the direction of shifting depending on whether the machine operates as a generator or as a motor. Figs. 4 and 5 represent a machine operating as a generator, for which the direction of current is downward (into the plane of the paper) in the armature conductors under the north pole for right hand rotation, and from Fig. 1 it is evident that the shift of

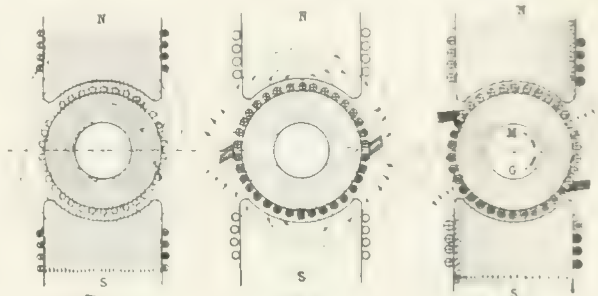

Fig. 3—Uniform field of force due to magnetomotive-force of field winding alone.

Fig. 4—Distribution of flux due to the current in the armature conductors only.

Fig. 5—Combination of fluxes from Figs. 3 and 4 showing actual load conditions.

the main field should be in the direction of rotation.

To change a direct-current generator feeding into a system, to operation from that system as a motor, involves only a reduction of its main field excitation. As

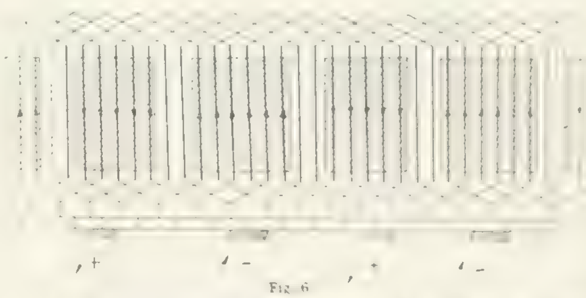

Fig. 6—Developed armature wiring diagram showing direction of current flow.

soon as the generated voltage of the machine falls below the voltage of the system, current will flow to instead of from the machine. Motor action, therefore, as contrasted with generator action, means a reversal of the direction of current in the armature conductors, but not a reversal of the direction of rotation.* The

*The explanation of this is apparent from Fig. 1. The direction of flux is indicated as under a North pole, so that for right hand rotation the direction of current in conductor *A* (downward) corresponds to generator action. As a motor, the armature current is reversed, as illustrated by conductor *B*; the magnetic reaction is therefore correspondingly reversed. As the torque of the motor is due to the tendency of the magnetic lines of force to repel one another and thereby push any disturbing factor from the stronger to the weaker region of influence, the force on the current carrying conductors will in this case also be to the right, the same as noted previously as a generator.

operation of small direct-current balancer sets very aptly illustrates this condition. It will be noted from Fig. 1, however, that the direct result of reversing the direction of current flow in the conductors is to reverse the direction in which the main field distortion takes place and the field shift is now against the direction of rotation as a motor. This distortion of the main field has an all important bearing on the operating characteristics of a machine.

EFFECTS OF DISTORTION ON COMMUTATION

In the collection of current at the brushes, the direction of current flow in the conductors is reversed as

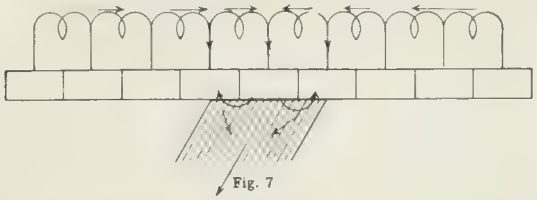

Fig. 7—Diagram showing direction of current flow in short-circuited coils.

the commutator bars to which they connect pass beneath the brush. This is indicated in Fig. 6 and diagrammatically in Fig. 7. Moreover, the fact that a brush can touch two or more bars at once means that during this period the coils are short-circuited. It is evident that even a low voltage induced in the conductors during short circuit, when applied to the extremely low resistance of the armature coil and brush contacts, will cause a heavy local current flow, and under these conditions, the rupture of these currents as the segments pass out from under the brushes will cause serious sparking. For this reason it is necessary that the brushes be so located that during the period of short-circuit the conductors shall lie in a region of approximately zero flux; viz., midway between the poles, when there is no distortion. This point is known

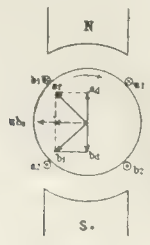

Fig. 8

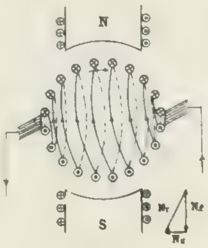

Fig. 9

Fig. 8—Vector diagram showing resultant magnetizing action of individual armature coils.

Fig. 9—Schematic diagram of armature connections with brushes on no-load neutral and vector diagram indicating the resultant combination of fluxes. N_f=main field flux. N_c=cross armature flux. N_r=resultant flux.

as the "no load neutral" setting of the brushes. As the load comes on, however, the magnetic distortion of the main field, Fig. 5, causes a shifting of the general direction of the flux, and a consequent displacement of the zero flux position. To compensate for this condition it is necessary in many of the old type non-commutating pole machines to shift the brushes to the new zero flux position, or at least to some point that represents the best average conditions of commutation over the load range of the machine.

ARMATURE MAGNETIZATION.

The actual magnetizing of the individual armature coils may be indicated as in Fig. 8. The coils a_1 a_2

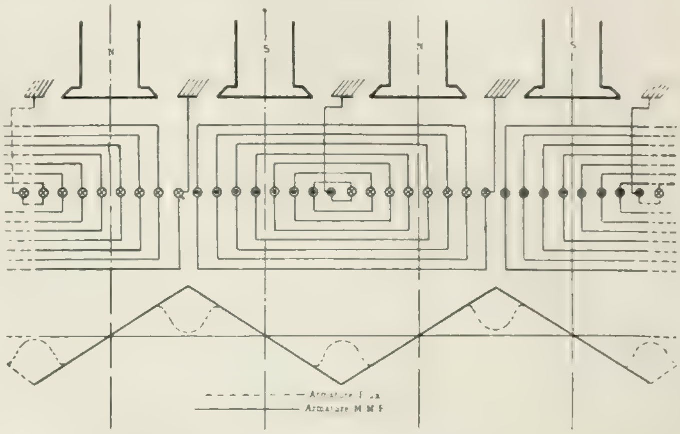

FIG. 10—DEVELOPMENT OF AN ARMATURE WINDING PRODUCING A FLUX SIMILAR TO THAT IN FIG. 9

Showing the corresponding armature magnetomotive-force and flux.

and b_1 b_2 produce the magnetomotive forces a_t and b_t respectively, which may be subdivided into the combined cross-magnetizing components, ab_c, and the demagnetizing components, a_d and b_d, the latter being in

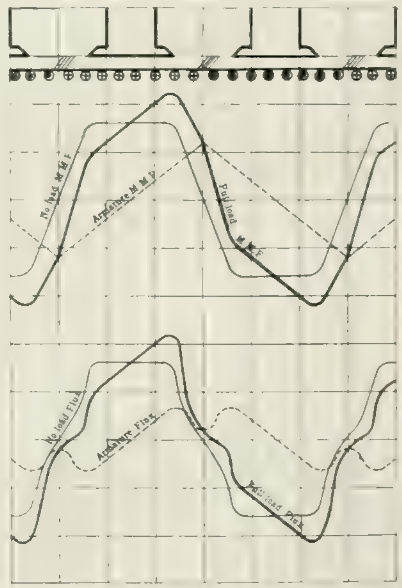

FIG. 11—MAGNETOMOTIVE-FORCES AND FLUXES FROM ARMATURE AND MAIN FIELD

opposite directions and thereby neutralizing each other. It is evident from this that the effectiveness of the coils in their reaction on the main field is dependent upon their position with respect to the poles.

Considering the total effective armature reaction of all the coils, it is necessary to distinguish between the two cases:—reaction without brush displacement; and reaction with brush displacement. For the first condition, the armature, although actually wound as indicated in Fig. 6 (multiple) may be represented as if excited as shown in Fig. 9, setting up a resultant magnetomotive force and flux as indicated in the vec-

tor diagram. Represented in a slightly different manner, this excitation may be considered as if produced by a single winding, Fig. 10, which remains in a constant location. In each belt of armature conductors carrying current in the same direction as shown in this figure, there is a conductor on one side of the center line of the main pole for every one similarly located on the other side of the center line, and the demagnetizing components of each such pair of con-

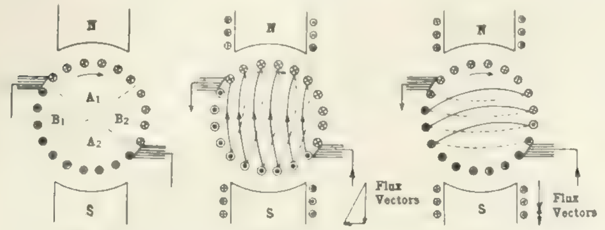

Fig. 12—Displacement of conductor belts due to shifting the brushes to the load neutral.

Fig. 13—Conductor belt giving cross-magnetizing effect only.

Fig. 14—Conductor belt giving demagnetizing effect only.

ductors neutralize each other, as explained in Fig. 8, leaving cross-magnetization only as the resultant armature influence when the brushes are located on the no-load neutral. The combined full-load magnetomotive forces of both armature and field with brushes on the no-load neutral, and the resultant modification of the flux distribution are illustrated in Fig. 11.

EFFECTS OF BRUSH DISPLACEMENT

Shifting of the brushes materially alters the above relations. The first point of difference is the displacement of the conductor belts carrying current in the same direction, to an unsymmetrical position with respect to the center line of the poles, Fig. 12. As a result, the demagnetizing components of the individual turns as indicated in Fig. 8, are only neutralized for those turns still symmetrically located with respect to the pole centers, that is, in the angle A_1 and A_2, Fig. 12. Applying the same analysis to the armature turns located in the double angle of brush displacement, B_1 and B_2 in Fig. 12, it will be observed that in this case it is the cross-magnetizing components which are neutralized, and the demagnetizing components which remain to give a resultant reaction on the main field. Two distinct groups of conductrs exist, which may be more clearly distinguished if represented as though excited by entirely separate series windings, Figs. 13 and 14, the vectorial combination of their magnetomotive forces with that of the main field being shown in Fig. 15. The combination of the magnetomotive forces and the resulting flux distribution in the air-gap with the brushes displaced, is indicated in Fig. 16, and is observed to be similar to that with the brushes on the neutral, Fig. 11, except for the demagnetization and the neutral displacement with respect to the poles.

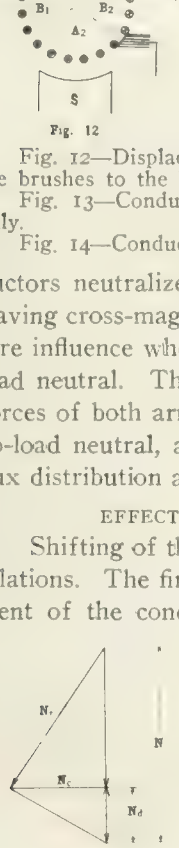

Fig. 15

Fig. 15—Vector diagram showing combination of the separate effects indicated in Figs. 13 and 14. N_f=main field flux. N_c=cross armature flux. N_d=demagnetizing armature flux. N_r=resultant flux.

EFFECTS OF ARMATURE REACTION

In operation, the effects of armature reaction are only apparent in the conditions of commutation. Extreme distortion corresponding to a sharply peaked field form, results in excessive voltage induced be-

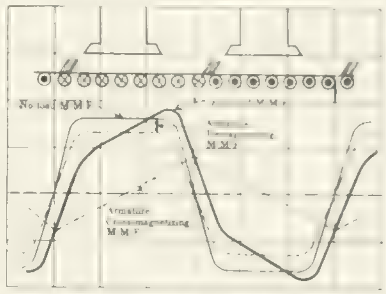

Fig. 16—Diagram of magnetomotive forces

Similar to that in Fig. 11, except that the brushes are now shifted to the load neutral position.

tween commutator bars, and this may cause serious arcing or even flash-over under variable loads or voltage.* Excessive neutral shifts with fixed brush position occasion constant sparking and spitting at the brushes. Less direct results are:—

1—Blackening and burning of the commutator with excessive temperature rise.

2—Rough surface and reduced commutator life.

3—Excessive local currents and increased armature heating.

4—Rapid wear and deterioration of the brushes.

MEANS EMPLOYED TO REDUCE REACTION EFFECTS

Among the first expedients adopted to limit the field distortion due to armature reaction was the saturated pole tip. For this purpose, the pole is assembled from laminations which have been punched without tips at one end and then assembled with tips alternating from one side of the pole to the other. As a result the area of magnetic material in the flux path is reduced and the flux density greatly increased. The field magnetomotive force required is correspondingly higher and for the same armature strength the effect of the reaction may be much reduced. Similar action has been secured by the use of pole laminations with horizontal or vertical slots near the tips, also by making the pole faces eccentric at the air-gap, giving a wider gap at one or both tips than under the center of the pole.

In nearly all recently developed types of direct-current machines, the commutating pole has superseded other means of counteracting the objectionable features of armature reaction. As the commutating poles are excited by a winding in series with the armature, a relatively exact compensation is obtained over the entire load range in the absence of magnetic saturation in the commuating-pole circuit; and as a result the neutral of position of best commutation is practically a fixed point for all loads.

*See article on "Flashing in Railway Motors" in the Journal for October, 1913, p. 1942.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1007—Interconnected Star — Please furnish a diagram for the interconnected star method of connecting up transformers. Under what conditions is this connection useful?

B. D. L. (D. OF C.)

Ordinarily this connection is used only with rotary converters when it is desired to derive a neutral from a three-phase bank of transformers for a three-wire direct-current circuit. The primary sides of the transformers may be delta or star connected and the secondary connected as indicated in Fig.

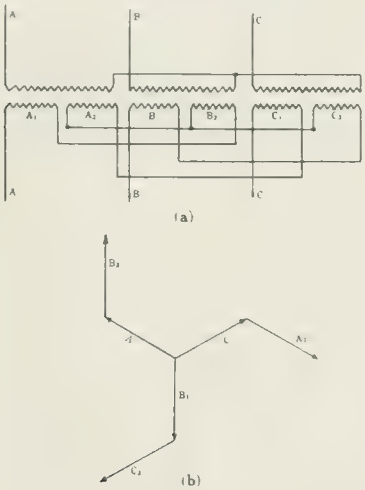

FIG. 1007 (a) and (b)

1007 (a), the current and voltage relations being as shown in Fig. 1007 (b). The direct current in an ordinary star-connected group would cause the magnetic circuit to be greatly unbalanced, i. e., highly saturated at one alternating-current maximum and only slightly magnetized at the maximum in the reverse direction. In the interconnected group, the direct current in the two halves of the winding counter-balances, producing zero total magnetizing effect, so that there is no unbalancing of voltages or magnetic fluxes. This method of connections also is sometimes used where it is desired to derive the neutral from delta-connected generators or transformers by means of auto-transformers. With an unbalanced load, the voltage regulation will be considerably better than with the ordinary star connection, since the load will still be divided on all three phases of the primary, although, not equally. For this reason the use of regular transformers and the delta-star connection is preferable. On account of the phase displacement between the voltages in the two halves of each transformer secondary, the capacity of the secondary winding on each transformer must be 15.5 percent greater than the primary or of the secondary of a transformer connected in the ordinary manner. Similarly the capacity of auto-transformers connected in this manner must be 15.5 percent greater than if they were connected in the ordinary manner for the same kilowatt-amperes output.

W. M. M.

1008—Paralleling Alternators — Two units with leads *A, B, C* and *D, E, F* are to be phased out. If, on connecting *F* and *C* the difference of potential between *E* and *B* and *A* and *D* is found to be zero, is this sufficient evidence of the correctness of the connections?

C. O. V. D. (QUEBEC)

Zero potential between phases *A* and *D* and *B* and *E* is sufficient evidence of correct connections between synchronous machines when both are operating at normal voltage.

C. R. R.

1009—Changing 2300 Volt Two-Phase Generator to 575 Volts Three-Phase —With reference to No. 937 would like to inquire (a) just how to alter the connections so as to get exactly 575 volts (excitation and speed remaining the same as before)? (b) What arrangement will give the best results? We do not wish to go to the expense of getting a new winding, which is of the two coil per slot "barrel" type.

G. E. S. (CANADA)

The coils should be reconnected in the form of a three-phase star winding and each phase divided into five groups of eight coils each. The groups should be so arranged that a winding is obtained consisting of five equal stars connected together at the terminal and neutral points. Working the generator magnetically the same as before, this winding will give a terminal voltage of 564 volts.

R. K.

1010—Single-Phase From Three-Phase Circuit —The writer visited a foundry in Chicago having an electric furnace, which operated single-phase, the current being taken from a commercial three-phase power circuit. Kindly explain how this is done.

J. D. M. (OREGON)

The connections at the foundry mentioned are given in Fig. 1010 (a), through courtesy of the Commonwealth Edison Company. This connection gives a balance on the primary so far as the current is concerned, but the current and voltages in the primaries of two of the transformers are 60 degrees

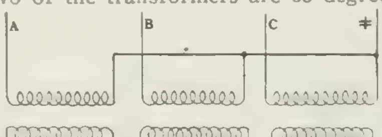

FIG. 1010 (a)

out of phase at unity power-factor of the load. This is a very similar condition to that described in No. 958 for the two-phase circuit, and single-phase, i. e., pulsating, power only is taken from the generator. On a large system, the amount of unbalancing is apparently too small to be noticable.

C. R. R.

1011—Acceptance Test — Please let me know the method of figuring losses in connection with the acceptance tests of large synchronous and induction motors, where these are connected to centrifugal pumps. These tests are to be made in a city pumping station and are to be official acceptance tests.

H. A. A. (ONTARIO)

Tests to be performed on synchronous motors for a complete determination are core-loss, no-load saturation, short-circuit loss and saturation, friction and windage, resistance of armature and field windings. Corresponding tests for an induction motor consist of locked saturation test, running saturation test, resistance of primary and of secondary, if of the wound type. These tests furnish sufficient data from which to determine complete information concerning the motor by means of circle diagrams. For details of these tests, see series of articles now running in the JOURNAL on "Shop Testing of Electrical Apparatus."

P. E. H.

1012—Surges on Transmission Line A transmission line consisting of two 2/0 stranded copper circuits is arranged as in Fig. 1012 (a). The line is about 30 miles long and can be sectionalized at the middle point by means of disconnecting switches as indicated in Fig. 1012 (b). Suppose a break occurs at point *C*. The sectionalizing switch is then open on circircuit *B* and the load carried on circuit *A*. When the lightning arresters

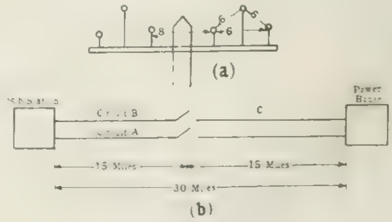

FIG. 1012 (a) and (b)

are charged at the sub-station twice a day, circuit *B* is alive during the charging period from the sub-station as far back as the sectionalizing switch. Will the charging of the arrester on circuit *B* have any effect on the system due to the fact that the circuit is open at the middle point, or in other words, will there be any tendency to start a surge when the arrester is charged.

C. O. V. D. (QUEBEC)

There will be some tendency to setup oscillations when the arresters are charged, but we should not expect them to be seriously dangerous to well insulated modern transformers. The oscillations could be minimized by disconnecting circuit *B* from the sub-station by means of disconnecting switches when charging the arresters on circuit *A*. The use of charging resistances,

which are in series with the arresters during the charging only, would also reduce any tendency to oscillation by making it a non-oscillatory circuit due to the presence of the damping resistances. Q. A. B.

1013—Resultant Power-Factor—What is the resultant power-factor of an induction motor rated at 80 percent power-factor at full load if it is connected to a circuit of 65 percent power-factor? Can the power-factor of a given load be corrected by a single generator of sufficient capacity which furnishes power to the load? R. W. W. (IND.)

The power-factor of an induction motor or of any other individual piece of apparatus is entirely independent of any other apparatus connected to the same line; the power-factor of the line is equal to the vectorial average of the power-factors of the apparatus connected to it. The power-factor of a load cannot be changed in any way by any apparatus apart from the load. Power-factor correction by synchronous motors, over excited, is sometimes very beneficial by increasing the carrying capacity of a line or of a generator, but has no effect upon the apparatus connected to the line except as improved regulation of the line affects apparatus. C. R. R.

1014—Collector Rings for Acyclic Generators.—Three hundred amperes is safely carried by a single trolley wheel under very rough conditions. Why could not rolling contacts be employed in acyclic or turbo-generators where the surfaces could be much better than with the trolley wheel? M. L. P. (ILL.)

Rolling contacts would be possible, but sliding contacts are required to take the current off the rollers; this means double collection. Usually a stationary brush will collect the current with less total loss. B. G. L.

1015—Switchboard Connection—In Fig. 8, p. 165 of the JOURNAL for Feb., '13, panel No. 4 shows direct-current connections from the rectifier, including two oil switches, relay, lamp and ammeter. Will you please explain the object of the connections as shown, i. e., the use of two switches, the ground connection through one pole of one switch, etc. W. T. H. (MONT.)

The line running from the grounded poles of the oil switch to the ammeter should not have been shown. The correct connections are shown in Fig. 1015 (a). Switch No. 1 is a primary switch and connects the alternating-current leads of the rectifier outfit to the bus-bars. Switch No. 2 is the starting switch. It is first closed and the direct-current side of the rectifier is short-circuited for about two minutes in order to allow the bulb to become heated so that it will hold its load. Switch No. 3 is then closed and No. 2 is opened. The relay is normally energized when the rectifier is loaded. In case of a broken wire or the bulb going out, the core or the relay drops and closes the contacts to an alarm circuit. The lamp is connected in the series circuit and is mounted on top of the panel giving visual indication that the rectifier is working correctly. This lamp is not in circuit during starting. The ammeter is of the series type and is connected in the direct-current circuit in both the starting and running positions. H. A. T.

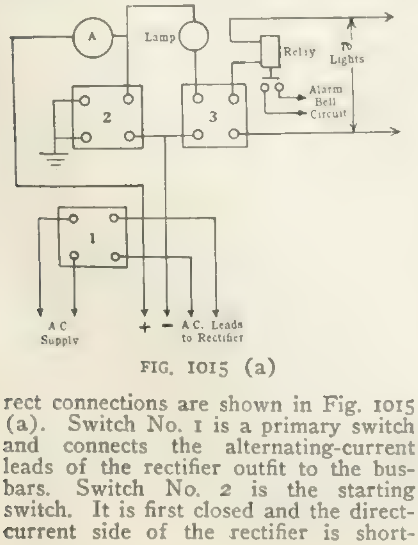

FIG. 1015 (a)

1016—Series Arc Generators—Is it present day practice to use series direct-current generators for series arc lamps or for series incandescent lamps? Is not the tendency to use alternating-current lamps (arc) with constant-current transformer? Are series direct-current generators manufactured much now? P. C. (RHODE ISLAND)

Very few series direct-current generators are manufactured or installed at the present time, and although a considerable number of machines are still in use, they are rapidly becoming obsolete. The present tendency is to use alternating-current series arc lamps of either the enclosed carbon or the enclosed flame-carbon types, with constant-current transformers or metallic-flame direct-current series lamps with a mercury arc rectifier. T. J. P.

1017—Paralleling Three-Phase Transformers—As described in Mr. McConahey's article in the JOURNAL for July, 1912, p. 618, three-phase transformers can be paralleled by jumping together two poles on the oil switch and putting a transformer and voltmeter across the other two pairs, which will read zero if the leads are rightly arranged, and double line voltage in case of a crossed phase. They may also be paralleled by omitting the jumper altogether and simply putting the transformer and voltmeter across each pair of poles successively. In the case of a crossed phase the voltmeter will read line voltage, being apparently the resultant of the two voltages to ground combined at 120 degrees. When using the first method, if a crossed phase exists the capacity current will flow through the jumper, and I am informed that there is a danger of having this blown if it is not made of suitable size. For instance, a No. 4 wire jumper was blown on a 3 000 k.v.a. transformer. Please give a rough idea of the magnitude of the capacity current flowing on, say, a 3 000 k.v.a. transformer, 12 000 to 22 000 volts J. P. (ALBERTA)

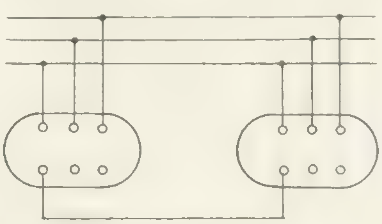

FIG. 1017 (a)

In making the polarity test, the transformers should be connected in a manner similar to that shown in Fig. 1017 (a). A jumper is connected across one pair of terminals in order to form an electrical connection between the wind-[illegible] If this is not done, the voltages measured between the terminals of the two transformers will bear no fixed relation to one another. It is true that, if the phase relations of the voltages across similar terminals of the two transformers are not all the same, there will probably be a capacity current flowing through the jumper. This current should be small and we can see no reason why it should be sufficient to blow a No. 4 wire. A much smaller wire should ordinarily be sufficient. W. M. M.

1018—Lightning Protection—I have a three-phase, 60 cycle, 2 300 volt transmission line, three miles long. There are 110 poles in the three miles. On every fifth pole there is installed on each wire a multi-gap pole-type arrester and a good ground rod. At one end of the line a set of choke coils is installed, and on each phase three sets of multi-gap pole-type arresters. This is at the main switchboard. At the other end of the line a set of transformers changes from three-phase to two-phase current. I would like your opinion as to whether it is necessary to install choke coils and another set of three arresters on each phase before going into the transformers. J. G. D. (RHODE ISLAND)

Lightning has long been known to be too freakish to allow of making positive statements that any given arrangement will or will not give complete protection. If there are arresters on the last pole before the sub-station there should be little need of additional arresters in the station, while if the nearest arresters are five poles away, station aresters might prove valuable. Choke coils at the sub-station are desirable if the transformers are not of recent design. They will help in any case, but on a fairly well protected line like this they would not be so necessary if the transformers have the good insulation common in recent designs. Q. A. B.

1019—Vectorial Relations in a Transmission Line—We have a three-phase, 60 cycle, 10 000 volt generator feeding a transmission line which has a charging current of ten amperes without any transformers or load of any kind connected. Assume that there is no leakage between phases or from phase to ground. Now, if at the end of the line, a bank of

FIG. 1019 (a)

transformers is connected which draws a no-load current of such a value and at such a power-factor that the 90 degrees out of phase component is ten amperes: (a) Will the current in the line be in phase with the e.m.f.? (b) Will the value of the current in the line be just sufficient to represent the iron and copper losses in the transformers and line? (c) Will the different location of the bank of transformers on the line make any difference as to the current and voltage relations and the value of the current supplied by the generator? C. M. P. (ALASKA)

(a) The current at *A*, Fig. 1019 (a), will be in phase with the e.m.f. (b) The current at *A* will be of just such a value as to represent the true energy flowing into the system. As we depart from *A* toward *B* the power-factor will become more and more lagging. (c) The location of the transformers will not affect the power-factor conditions at the generator or at the transformer, but may affect the power-factor as measured at other points. P. M. L.

1020—Transformer Connections —Three transformers, *A*, *B* and *C*, of the same capacity, are connected in delta on primary and secondary sides. Two equal loads are connected on the secondary feeders as shown in Fig. 1020 (a). Will transformer *C* take any load? What effect will the unbalancing of the loads have upon the load of each transformer? L. R. M. (MANITOBA)

The loads will be, for each ampere of load on the two loaded phases five-sixths of an ampere on transformers *A* and *B* and one-third of an ampere on transformer *C*. The current for a single-phase load connected to a three-phase circuit, such as shown, may be considered, if the load is on phase *A*. as having two parallel paths through the delta mesh, one through trans-

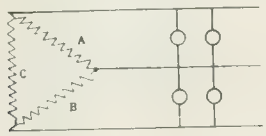

FIG. 1020 (a)

former *A*, and the other through transformers *B* and *C* in series. If the transformers all have equal impedances, two-thirds of the current will flow through one circuit and one-third through the other circuit. The load produced on the individual transformers by two single-phase loads on different phases will equal the vectorial sum of the loads produced by each of the single-phase loads. C. R. R.

1021—Design of Magnets —I am interested in data on the design of plunger electro-magnets. Underhill in his book on "Solenoids," as well as the Standard Handbook, give formulae for the pull of a plunger electro-magnet which are essentially the same, namely :— $\frac{P}{A} = \left(\frac{NI}{2660\, l}\right)^2 + \frac{0.096NI}{L}$ where *NI*=ampere turns, *P*=pull in pounds, *l*=length of air-gap, inches, *A*=area of core, sq. inches, *L*=length of winding. Wikander in Trans. A. I. E. E., Vol. 30, June, 1911, derives formulae for electro-magnets, which are based on a set of curves, Fig. 6, p. 2038, from tests of an actual magnet. Calculations of the coil with the above formula do not check with these curves. For instance, with 29 200 ampere-turns, 1.5 inch air-gap, and length of coil 8.5 inches (by scale from the cut of the coil), the above formula gives P/A=(54 plus 33)=87 pounds, while the curves show P/A =70 pounds. Will you please tell me the limitations to be observed to make the curves and the formula agree. G. L. H. (CALIF.)

The values of magnetic pull obtained by the various methods of calculation seem to agree fairly well considering that the formula given in the Standard Handbook assumes that the length of the magnet core is more than ten times its diameter, while the magnet to which the curves in the A. I. E. E. Transactions refer is designed with a length of core slightly exceeding four times its diameter. The ratio of core diameter to inside diameter of the shell has also an appreciable influence on the pull, but this ratio is not taken into consideration in the above formula. It is to be regretted that so little data on the subject has been published, and it would be of great benefit to designers of magnets if some person would make a series of tests of the pulls of magnets of various shapes, plotting the curves against the ampere-turns for various air-gaps. R. W.

1022—Single-Phase Motor Trouble —A single-phase motor, started by a combination of reactance and resistance, was badly heated by putting the starter on the running side, while the motor was at rest. Solder was thrown from the rotor, but the stator seems to be in good shape. After resoldering the rotor, the machine runs up to speed, but will not carry its usual load. What is the probable cause? C. W. (NOVA SCOTIA)

A single-phase motor differs from a polyphase motor in that a change in the secondary resistance affects not only the speed but also the maximum or pull-out torque, and it is probable that in resoldering the rotor it has not been put in quite as good shape as it was originally and the increase in resistance so caused is reducing the pull-out torque. If the rotor winding is rebuilt and put in its original condition again, the motor will probably have the same torque characteristics as at first, barring possible injuries to the primary winding due to over-heating, which could be located and corrected by the usual means. A. M. D.

1023—Sixty Cycle Transformers on Twenty-Five Cycles —In attempting to use 60 cycle transformers on 25 cycle lines, some curious points have been noted, namely, that some makes and sizes of transformers cannot be used at all, while others work satisfactorily, but with poor regulation and considerable heating. Can you give any suggestion for a practical method of adapting 60 cycle transformers for the other service; efficiency being disregarded, the sole idea being to keep the work going. Our transformers are 2 200 to 220-110 volts and it has been suggested to reconnect the primaries for 1 100 volts and use two in series. I fail to see how this can improve matters. W. L. F. (CANAL ZONE)

The points which you have noted in attempting to operate 60 cycle transformers on 25 cycle lines are only those which are normally to be expected. The formula for the voltage of a transformer is $V = \frac{4.44\ A\ B\ Nf}{10^8}$, where *A*= the cross-sectional area of the magnetic circuit in square inches; *B*= the induction in lines per square inch; *N*= the number of turns on the winding to which is applied the voltage *V*, and *f* is the frequency in cycles per second. From this it will be observed, maintaining all other conditions constant, that the induction varies inversely as the frequency. It has been found by experiment that the core loss of transformers varies approximately according to the 1.7 power of the induction, while the magnetizing current varies almost directly as the induction as long as the iron is worked below the saturation point, these values increasing very rapidly when the saturation point is passed. From this it will be noted that when the frequency is lowered, the core losses and the magnetizing current both increase at a very rapid rate, and in a 60 cycle transformer which is conservatively designed, these losses become high enough to cause sufficient heating to destroy the transformer even when it has no load. The reason certain 60 cycle transformers are able to operate on 25 cycles is that they are designed with such a liberal amount of iron that the induction remains below the point of saturation even when the frequency is reduced to 25 cycles. From the above formula it will be noted that the induction also varies inversely as the voltage. Consequently, if the frequency is cut in half, and the voltage is at the same time reduced to one-half its previous value, the induction should remain the same. This is roughly what happens when a 60 cycle, 2 200 volt transformer is operated on 1 100 volts at 25 cycles. Hence, the suggestion that you operate two transformers in series on the primary and parallel on the secondary is a good one, the primaries being connected for 2 200 volts so as to receive one-half normal voltage. By this means the induction is only slightly increased—not sufficient to burn out even conservatively rated transformers. C. R. R.

1024—Mercury Rectifiers —What is the best material for use in lead-in wires in a mercury rectifier with silica tube? (b) What feature limits the current capacity of these tubes to 50 amperes; the electrodes, the vapor temperature or the distribution from the container? M. L. P. (ILL.)

(a) In general, platinum is the only commercial material used as a seal-in wire through any vitreous container. Where it is used on silica (quartz) an intermediate glass has to be used between the quartz and the platinum. Some progress has been made in the use of tungsten and molybdenum as seal-in wires through glasses of low expansion similar to quartz and it is likely that one or the other will come into use sooner or later for this purpose. (b) There is no particular limit to the size of a rectifier, but it becomes very difficult and expensive to produce one of glass for current above 50 amperes. Metal rectifiers have been built for much larger current. R. P. J.

1026—Critical Speeds in Turbo-Generators —Please outline a simple method used to calculate the critical speeds in turbo-generators. M. L. P. (ILL.)

So far as we know, there is no simple method of calculating critical speed for commercial generators. There are, however, several formulae which are comparatively simple for certain types of rotors. See Stodola's treatise on "Die Dampfturbine" which has been translated into English. In manufacturing concerns where comparative test data is available on machines of certain definite types of construction, critical speeds can be estimated with fair accuracy by direct comparison of the principal design proportions of individual machines. R. E. G.

THE ELECTRIC JOURNAL

VOL. XI FEBRUARY, 1914 No. 2

The International Edition

For a number of years subscribers to the JOURNAL in Europe, Asia and Africa have been supplied with a special edition of the JOURNAL known as the "International Edition," issued from the London office. This edition, while containing the same editorial matter, had different advertising pages and a different cover. Numerous foreign subscribers have specifically requested that they be sent the American edition and such requests have been complied with. This, however, has led to confusion in the mailing lists and, while making the change in page size, it has been decided to change the arrangement with reference to foreign subscriptions so that all will receive the regular American edition.

It is gratifying to find engineers outside of the United States taking so kindly to the JOURNAL, there being at present over 2 200 copies per issue going outside the United States, with Canada first with 820, England second, and Japan third with 327 subscribers. While the material published is necessarily designed for the American engineering public, a very considerable part of the reading pages relate to physical facts rather than to specific practice in one locality, and hence are of value to engineers wherever located It has been the general experience to find that subscribers who are the farthest removed from the great industrial centers value their copies most highly. The JOURNAL is peculiarly fortunate in being located in the midst of one of the greatest engineering centers in the world and thus is in a position to present to its readers in distant localities the very latest developments in the electrical industry as seen by men actively engaged in practical engineering work.

The Analysis of Wave Forms

Every advance in methods and tools which permits a nearer approach to the ultimate best design of an electric device is a distinct benefit to the manufacturer and purchaser of electrical apparatus and to the consumer of electric current. It is of advantage to the manufacturer inasmuch as it gives him the means of meeting the required performance by the most efficient use of his materials, and at the same time producing a device which will give the greatest freedom from trouble. It is of advantage to the purchaser and user of the apparatus, as it gives him a cheaper, more satisfactory and more efficient device. It is of advantage to the ultimate user of electric current by giving him in the end more satisfactory and cheaper service.

Of such character are the devices described in this issue of the JOURNAL by Mr. L. W. Chubb. These devices are notable not because they give us a new product or a new result, but because they furnish new tools which greatly facilitate the getting of results hitherto obtained only by very considerable labor. Furthermore, numerous tests have shown that, on the average, the new tools give results of greater accuracy than are usually obtained by even a worker skilled along this particular line.

The very ingenious methods described, of recording and analyzing electric waves, should greatly stimulate the analysis of wave forms in general and should give us the true cause for many phenomena heretofore considered obscure. The discovery, for example, that the electromotive-force wave from a certain machine contains a very large proportion of higher harmonics, shows at once the necessity for a change in design, indicates what these changes should be and, at the same time, explains the exact cause of the difficulty encountered. Although the mathematical theory of the analyzer may seem somewhat complex, the apparatus itself is beautifully simple and easy to operate. The original instrument has been in constant use for over a year, and has been found eminently satisfactory.

C. E. SKINNER

Testing Induction Motors

The tests to which any piece of electrical apparatus may be subjected are those necessary to determine fully, its performance under service conditions. Such tests bring to light any defects either mechanical or electrical in its design or manufacture before the apparatus is placed in actual service.

In the case of induction motors, in addition to the heating limitations, such characteristics as efficiency, power-factor, slip, starting current, starting torque and maximum torque must be determined. Two general methods are available for this purpose;—first, their actual measurement by means of some form of brake; second, their computation based on certain simple tests as described in this issue of the JOURNAL. Brake tests are inherently subject to great inaccuracies. For commercial purposes, on account of the difficulty of properly dissipating the heat and of obtaining close regulation, the use of the brake is limited to motors of under 100 horse-power capacity. On account of these limitations, recourse is generally had to some form of computation, and there are almost as many forms as there are designing engineers. In all of them, due largely to the inability to measure

directly the voltage, current, power, etc., in the secondary windings under normal operating conditions, certain assumptions must be made. On the accuracy of these assumptions depends the accuracy of the results obtained. Hence, the assumptions are only justifiable when the probable error likely to result therefrom has been carefully investigated and found to be well within that liable to exist under the more direct methods of measurement, such as the brake test. These assumptions should also be of a general nature; that is, not dependent upon any particular type or design, or dependent upon some characteristic known only to the designer. Any method of performance computation to be commercially applicable must be capable of being worked out intelligently and accurately by men not experts in the higher branches of either engineering design or mathematics.

The circle diagram, as presented in the present issue of the Journal, conforms admirably to the foregoing requirements. The assumptions there involved become of consequence only in cases of high secondary loss, as in machines having over ten percent slip or in very small motors where the no-load losses are a large proportion of the total. In such cases, brake tests or the more complicated methods of computation give more accurate results. Such errors, moreover, as are introduced by the use of the circle diagram are on the safe side; that is, the actual performance will be better than that computed.

Testing operations, to be satisfactory, cannot be carried on mechanically or in absolute accordance with fixed rules. Rules should be followed where possible, especially in commercial work, as a proper respect for system tends toward efficiency, but the application of common sense and the ability to observe are essential. Perhaps the chief difficulty in testing operations is the matter of recording the data. In any record of test, more than a simple mechanical record of numerical results is necessary. The tester must always keep in mind that his record furnishes the only information covering the operation of the machine and it should convey to any one referring to it, as complete a comprehension of such operation as if he were actually on the ground.

The importance of thorough and reliable tests on any piece of apparatus cannot be overestimated. The manufacturer and customer each share the benefit. The customer is assured that the apparatus will satisfactorily meet his service conditions. The manufacturer determines whether or not his material has been used to the best advantage. As competition becomes more and more severe, refinements in design and in construction are essential. That changes made have been to the advantage of all concerned can only be demonstrated by such tests. E. I. Chute

Temperature Measurements

The reading of temperatures, while of unquestionable importance in the every day testing of electrical machinery, is apt to assume to the average tester a rather prosaic hue, the monotony of the proceedings being varied only occasionally by some puzzling inconsistency. Resistances of series field circuits, including connections between coils, for instance, have been known to measure consistently lower when hot than when cold, making the determination of temperature by the rise of resistance method of questionable value. The article by Mr. O. W. A. Oetting, in this issue of the Journal, which outlines some of the temperature conditions existing in modern electrical machinery, and some of the precautions which must be exercised in measuring them, should prove of value to every tester. It is especially valuable as an adjunct to the present testing series.

The method of testing internal temperatures outlined forms the first really practicable method of measuring the temperature of the copper and iron inside the machine. A complete solution of this problem involves the measurement of maximum and minimum temperatures attained in the various parts, together with the temperature gradient between them, as determined by the known characteristics of the materials involved, such measurements being entirely impossible with the ordinary thermometer. The data presented in curve form allows of a much more complete determination of the actual conditions with regards to the insulation temperature than has been possible heretofore by direct means, as well as indicating the direction of temperature flow, and thus makes possible a scientific determination of the ventilation requirements of such machines. Even by the method outlined it is not feasible to place the thermo-couples in direct contact with the copper of the coils on account of insulation difficulties, but the assumption that the mid point in the insulation between two coils carrying the same load and having approximately similar surroundings will reach the same maximum temperature as the coils themselves, seems entirely reasonable. Such determinations are, of course, of interest only to the designer, or to the user in so far as he cares to assure himself that they have been considered by the designer.

There is nothing new, of course, in the use of thermo-couples for temperature measurement. The valuable features of the type of couple described are its very small size, its sensitiveness to small changes in temperature at relatively low absolute temperatures, as compared with ordinary thermo-couples, and the fact that it is at once direct reading and independent of the resistance or length of the leads from the couple to the galvanometer. Chas. R. Riker

The Engineering Evolution of Electrical Apparatus—II

THE ALTERNATING-CURRENT GENERATOR IN AMERICA

B. G. Lamme
Chief Engineer
Westinghouse Electric & Mfg. Company

FOREWORD—The following article contains a fairly complete brief history of the evolution of the alternating-current generator in so far as the Company with which the writer is connected is concerned, as drawn from the writer's memory principally. Reference is made incidentally to the work of other manufacturing companies, but this cannot be very complete, as the writer naturally does not have the necessary material available for describing such developments, except in a very general way. Therefore, the inadequacy of this history, outside of the Westinghouse part, should be charged to the lack of data rather than to lack of respect for the work of others.

IN the early days of the alternating-current generator, it was constructed in almost as many types as there were designers. The principal endeavor of each designer appeared to be toward the development of a new alternator which would bear his name. A few of these early types were of the rotating field construction, while a much greater number were of the rotating armature type. Some had iron core armatures, while others had coreless armatures, and there were many discussions as to whether the core or the coreless type was superior and would survive. Many of the early predictions would now form quite interesting reading, in view of the fact that present practice is so far removed from the early anticipations. Here and there among the early machines was one which contained some of the important elements of recent apparatus, but in many cases such machines disappeared in the general course of development, the meritorious features being insufficient to save the type.

SURFACE WOUND ARMATURES

In America, the principal early type of alternator had a rotating armature with surface windings and an external cast iron multipolar field. This type was used very considerably or, in fact, almost exclusively, from 1886 to 1890. This was the type built by the Westinghouse and the Thomson-Houston Companies. There were only minor differences in the construction of the machines built by these two companies which, however, at that time, appeared to be very great. These differences consisted principally in the way the end windings of the armature coils were supported, in the construction of the end bells and ventilating openings in the armature core, in the method of attaching the armature core to the shaft, in the winding of the field coils in metal bobbins, etc. Both machines had surface windings with concentric coils, one layer deep in the radial direction. In the Westinghouse construction, the end windings were turned down toward the shaft and were supported by radial wooden clamps, as indicated in Fig. 1. In the Thomson-Houston armature, the end windings were arranged in an axial instead of a radial direction, and were supported by bands or external clamps. This construction is also indicated in Fig. 1. The Slattery machine, which was also on the market at that time, was of the same general type as the above machines. Presumably these two different methods of end winding were used on account of the patent situation. At that time there was much discussion of the respective merits of the two constructions.

These early machines were built principally for frequencies of 15 000 and 16 000 alternations per minute (125 and 133 cycles per second). In those days, everything was rated in alternations per minute, as this represented the product of the number of poles by the number of revolutions. Such high frequencies were selected, mainly, on account of transformer conditions, and not alternator design. Practically all alternating service consisted of house to house lighting, and in relatively small units, and the higher frequency was supposed to be of great advantage in transformer design and operation, which presumably was the case with the very small amount of data and experience available at that time.

About the only commercial voltage for alternating work at that time was 1 000 or 1 100 volts. This was supposed to be excessively high and dangerous, and there was much question whether such an excessive voltage should be permitted. This matter was actually taken before a number of the state legislatures for the purpose of obtaining laws prohibiting or limiting the use of such voltage. Another reason why no higher voltage was used was in the construction of the alternators and transformers. With the experience and materials available at that time, together with the high speed rotating armature construction and the surface windings, even 1 100 volts was a very serious problem in the generator. About 1889 or 1890, there appeared some slight demand for higher voltages, and a few 2 000 or 2 200 volt surface-wound alternators, of the then standard type, were built. However, even then it was recognized that the surface-wound type of alternator was not well adapted for higher voltages, and there was much question whether a different type winding should not be developed for 1 100 volts. This gradually led to the next big step, namely, the development of the "toothed" type of alternator with one big tooth per pole, in distinction

from the slotted type of armature with a number of slots per pole, which was a considerably later development.

TOOTHED ARMATURES

The first commercial toothed type of armature appears to have been gotten out by the Westinghouse

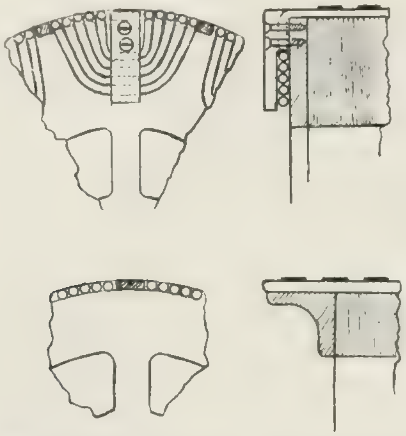

FIG. 1—SURFACE WOUND ARMATURE WITH RADIAL CLAMPS (UPPER) AND WITH AXIAL CLAMPS (LOWER)

Company. These first machines were radically different, in details of construction, from the later toothed armature types of machines which came into general use. The first toothed armatures were small air-gap machines. In the surface-wound armatures, the clearance between the armature surface and the field poles was comparatively small, although the total air-gap (iron to iron) was large on account of the surface winding. In constructing the new toothed armature, the actual clearance (iron to iron) between armature and field was kept about the same as in the surface-wound alternators (bands to iron), but this clearance actually represented the total air-gap in the toothed type. Moreover, in sinking the windings below the

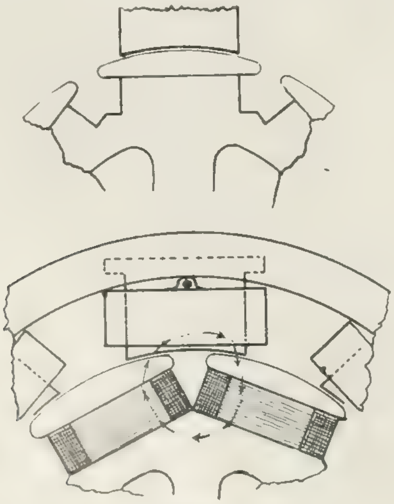

FIG. 2

surface, it was endeavored to maintain a practically uniform outside surface, so that overhanging tooth tips were used with relatively narrow slots for putting in the windings. The general construction was similar to Fig. 2. On account of the small clearance, and consequent higher magnetic conditions, it was found necessary to use laminated poles with these machines in order to avoid excessive field heating.

The self-induction of the armature windings on these machines was very high compared with the old surface-wound armatures and, therefore, in order to obtain passably good regulation, fewer armature turns had to be used, with correspondingly higher inductions, and this made the use of solid poles impracticable on account of heating. Furthermore, on account of the overhanging tooth tips, the small air-gap and the high induction per pole, this early type of toothed armature was very noisy. In one instance, it was credibly reported that one of these machines could be heard two miles away on a quiet night. However, several machines of this construction were put out by the Westinghouse Company, and operated for many years.

Meanwhile, the possibilities of the toothed armature construction in the old cast iron field were being given consideration. The writer made a special study of this matter, and finally decided that, in order to make this construction possible with solid cast iron poles, it would be necessary to work at relatively low

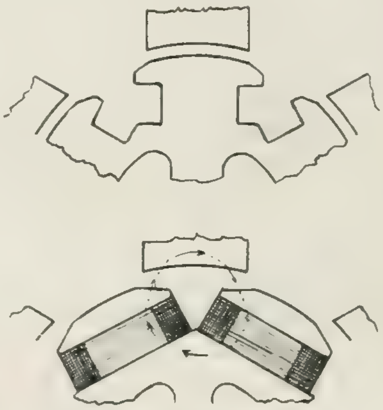

FIG. 3

inductions per pole, and with a very large air-gap, (fully as large as on the old surface-wound machines) and with a shape of tooth tip which did not have such great width compared with the pole tip as shown in Fig. 2. This meant that a pole tip and air-gap as shown in Fig. 3, should be used. With this arrangement, the armature self-induction would still be relatively high, and the regulation correspondingly bad, necessitating some form of compounding for regulating the voltage, similar to the compounding of a direct-current generator. This armature construction was worked out in detail for a 37.5 kilowatt field (that is, for the standard field of the 37.5 kw surface-wound type of machine). The armature teeth were similar to those in Fig. 3, in shape, and the air-gap or clearance from iron to iron, was made 3/8 inch on each side of the machine. The field was also compounded. When this machine was put on test, it was found at once that it could be loaded to 60 kilowatts without undue heating of the armature and field iron, and the problem of perfecting this machine then became one merely of increasing the amount of arma-

ture copper to carry the current at the 60 kilowatt rating. This, therefore, represented a big step in the development of the American type alternator. It was found that all the other Westinghouse standard cast iron machines of the rotating armature type could readily be changed in line with the above improvement.

COMPOUNDING ALTERNATORS

The compounding of the 60 kilowatt machine was not a new feature, for already some of the laminated field toothed-armature type of machines had been compounded, in order to improve their regulation. Two different methods of compounding alternators had been developed by the Westinghouse and Thomson-Houston Companies, respectively. In the Westinghouse armature construction, the armature discs were punched in single pieces, with spokes, and were threaded directly on the armature shaft, no spider being used. This construction is illustrated in Fig. 4. In the assembled armature, the spokes were therefore of laminated material. These laminated spokes were utilized as the core of a compounding transformer. One lead from the armature winding was carried around the spokes of the armature before passing to the collector ring. This winding formed the primary of a series transformer. The secondary was also wound on the spokes, and the two ends were carried to the bars of a rectifying commutator on the shaft. The number of commutator bars was equal to the number of poles. The alternating current from the secandary winding was by this means changed to a pulsating direct current.

In the Thomson-Houston method of compounding, the main armature current was carried directly to a rectifying commutator, and, after being commutated, was passed to the field-compound winding, and back to

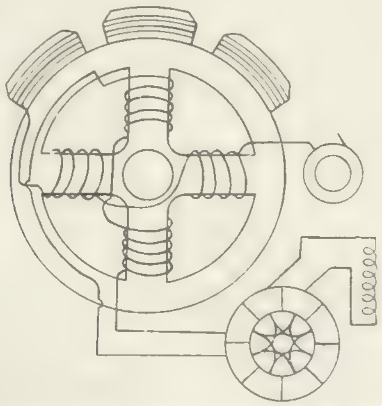

FIG. 4—SKETCH OF COMPENSATED TYPE OF WINDING

the commutator, and then to a collector ring. The main armature current therefore passed directly through the field, while in the Westinghouse method the secondary current from a series transformer was passed through the field. Both methods represented series compounding, and gave practically equal results, but there was much discussion as to the merits of the two methods. Both of these methods delivered pulsating direct current to the field winding. There was considerable inductive e.m.f. set up in the field windings by this pulsation, and this tended to cause inductive discharges across the rectifying commutators. In the Thomson-Houston method this trouble was overcome to a considerable extent by the use of a non-inductive shunt in parallel with the rectifying commutator, i.e.,

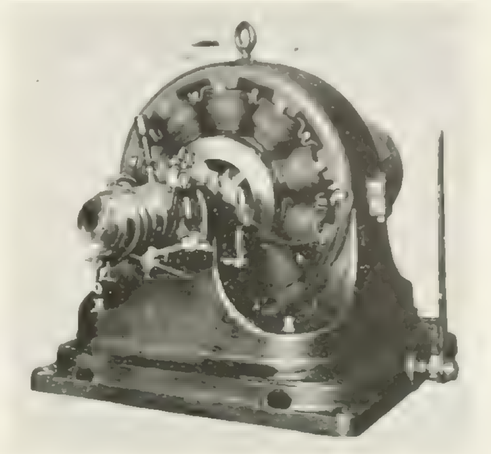

FIG. 5—EARLY WESTINGHOUSE 60 KILOWATT ALTERNATOR WITH COMPENSATING WINDING

across the compound winding. In the Westinghouse method a similar result was accomplished by saturating the series transformer (or armature spokes) to such a high point that the inductive kick from the field could readily discharge through the secondary winding of the transformer without giving high enough voltage to flash across the commutator.

The details of this method of compounding have been gone into rather fully, as this compounding was, at that time, an important step in our progress. The fact that of all these machines were built for single phase, allowed us to use such compounding. With the advent of polyphase generators, such methods of compounding soon disappeared, principally for the reason that a great majority of the early polyphase machines handled separate single-phase loads on the different phases, and it was not practicable to compound for these independently.

The above toothed type generator came into use about 1890 and lasted for several years, or practically until polyphase generators actually came into fairly general use before true polyphase loads became common. These toothed type generators allowed the use of relatively high voltages, as far as the armature winding was concerned, so that 2 200 volts became comparatively common, and even 3 300 volts or higher was used in some cases. In fact, the limit in such machines appeared to be at the collector rings, rather than in the armature winding.

Something may be said regarding the type of winding used on the armatures of these machines. In the Westinghouse construction the armature coils were machine-wound and taped before placing on the armature core. Each coil was made wide enough to slip

over the top of the armature tooth, as shown in Figs. 6 and 7. This made the coil considerably wider than the body of the armature tooth, so that, after slipping over the tooth top the coil had to be reduced in width by special clamping tools. Supporting wedges were then driven in between adjacent coils.

Something may be said regarding the temperatures of these early alternators, both of the surface-wound and of the toothed types. In those days temperature measurements were very crude compared with present practice, which is admittedly still only approximate. In some of the surface-wound armatures excessively high temperatures must have been encountered in many instances, judging from the appearance of the insulation on the individual wires, after a year's service, for instance. However, it was difficult to obtain reasonably correct temperature of the armature windings, for the actual temperature of the conductors was undoubtedly reduced very greatly before the armature could be brought to a standstill. Even after this, temperature rises of 50 or 60 degrees C. were not considered as excessively high. Without doubt, some of these early machines, at times, attained actual internal temperatures of 120 to 130 degrees C., or even higher, with insulation on the conductors con-

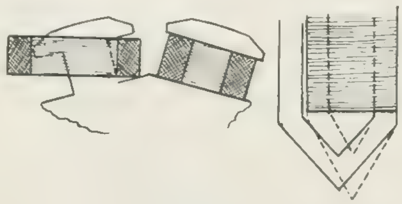

FIG. 6—SKETCH SHOWING METHOD OF PUTTING MACHINE WOUND COILS ON THE POLES

sisting of untreaded cotton fibre. No overloads were possible, for each size of machine was rated in as many "lights" as it could carry on a shop test without breaking down. The first few minutes, while starting up a new alternator in the testing room, were always anxious ones for the operators, especially so if any "improvements" had been made on the armature winding. Any defect in winding, or wrong connection usually resulted in a stripped armature and much flying copper. If nothing happened within the first few minutes after the machine was put on load, the attendants all came out from behind posts and other protections and went on with their work.

When the toothed armature came into use the above conditions were much alleviated. Defects in construction, or short-circuits, could not strip such armatures, and thus the danger and excitement were removed. However, it was found that the first short run did not tell the story of excessive heating as promptly as in the case of the surface-wound type. Experience showed that the toothed construction apparently could stand a severe shop test and still go wrong under similar loading within a short time after being installed. It was found that a given size of conductor would not carry as much current in the concentrated coils of the toothed construction as was the case in surface-wound coils. However, the method of testing the temperature did not show this, as the main part of the toothed armature coil was so embedded and so covered with insulation that the thermometer readings did not indicate nearly the true temperatures. The size of wire and the amount of copper in the coils then had to be increased until the machines did stand up in service. The true explanation of the discrepancies was not well understood at that time. In these toothed alternators, as in the surface-wound machines, the first machines were rated in "lights," but gradually the kilowatt rating came into use and became standard practice.

INTRODUCTION OF POLYPHASE ALTERNATORS

In 1892 and 1893, polyphase alternators began to be considered seriously. In 1889 and 1890, a few such alternators had been built for the operation of Telsa induction motors. These early polyphase alternators were of the surface-wound, rotating armature type. These machines were very special in construction, and, like the Telsa motors, did not find much of a market. However, in 1892 and 1893, it began to be recognized that the best way to encourage the development of the induction motor would be by creating a demand

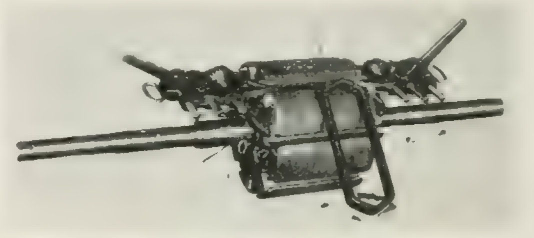

FIG. 7—VIEW OF ARMATURE IN PROCESS OF PLACING COILS AND CLAMPING THEM INTO SHAPE IN THE SLOTS

for it, and it was decided that a good way to create a demand would be by encouraging the general adoption of polyphase alternators and supply circuits, with the idea that, when a suitable supply circuit was available, there was eventually bound to be a demand for motors to operate upon such circuits. With this general policy in view, there was great activity in the development of polyphase generators. This very quicky led to a very considerable departure in armature construction from the usual toothed armature as used in single-phase machines. The polyphase winding, requiring two or more coils per pole, naturally tended toward the slotted armature construction with two or more slots per pole. It was soon recognized that, in general, the larger the number of slots per pole and the smaller the number of conductors per slot, the better would be the general characteristics of the machine, so that the construction naturally tended toward the modern slotted type. Moreover, practically all the development in polyphase alternators was at relatively low frequency, compared with former practice. It so happened that there had been a well-defined tendency toward lower frequency in the period from 1890 to 1892. This tendency was largely independent

of the induction motor problem for, at the time it became most pronounced, there was no true induction motor problem. It was becoming recognized that 125 to 133 cycles per second was too high for certain classes of work and for engine type generators, and that, in general, a very considerably lower frequency must eventually be adopted. A great many lower frequencies were tried by the different manufacturing companies, ranging from 50 to 85 cycles. However, 60 cycles seemed to have the preference at the time polyphase alternators began to come in.

The early polyphase generators were mostly of the rotating armature type, and usually with a fairly large number of slots per pole. One notable exception was the "monocycle" machine which usually had only two slots per pole, one large slot for the main armature winding, and one smaller slot for the so-called "teaser" winding. Also, the early two-phase alternators of the "inductor" type, built by the Stanley-Kelly Company, frequently had only two slots per pole. However, it may be said that, from 1893 to about 1898, the great majority of the American built alternators were of the rotating armature type with distributed armature windings. The principal exceptions were the Stanley inductor type of machines and a few special "rotating field" machines, as distinguished from the inductor type.

The rotating armature machines were usually of 1 100 or 2 200 volts, although a few of considerably higher voltage were constructed. A few cases may be cited where special constructions were used. For instance, the principal lighting plant at the Chicago World's Fair in 1893, consisted of a large number of Westinghouse "twin" type generators. Each unit had two single-phase, standard toothed type armatures side by side on the same shaft. The teeth of the two armatures were staggered 90 electrical degrees with respect to each other, so that the two together could deliver currents having 90 degrees relation to each other. The object of this construction was to obtain polyphase current with standard single-phase types of machines without any radically new development. This type of unit did not persist and, in fact, was simply an expedient for this particular occasion.

THE FIRST NIAGARA GENERATORS

Also, in 1892 and 1893, the first large Niagara electrical development was worked out. The advisory engineers of this plant proposed 5 000 horse-power generators, having stationary internal armatures and rotating external fields to obtain large flywheel capacity. In fact, the construction was not unlike the usual rotating armature machine of that period, as far as general appearance of the armature and field cores and windings were concerned. However, the method of supporting and rotating the heavy external field at a speed which, at that time, was considered excessively high, required an "umbrella" type of field support, which gave these machines a distinctive appearance. This type of construction did not persist, although these early machines are still in operation.

A further distinctive feature in these first Niagara machines was in the frequency employed. A speed of 250 revolutions per minute was decided upon. The engineers of the power company proposed eight pole machines, giving 2 000 alternations per minute or 16 2/3 cycles per second. The Westinghouse Company proposed, as an alternative, 16 poles, giving 33 1/3 cycles, the advantages claimed for this frequency being that it was better suited for motors and rotary converters, which were then promising to become of importance. One advantage claimed for the 16 2/3 cycle machine was that it would permit the use of commutator type alternating-current motors. After much discussion, and weighing and balancing of all the various arguments for and against these two frequencies, it was finally decided to use 12 poles, giving 3 000 alternations per minute, or 25 cycle polyphase current and, as far as the writer knows, this was the origin of the present 25 cycle standard.

Considering what a radical departure from ordinary construction was made in these first Niagara generators, it is self-evident that many curious and interesting conditions developed during their design, construction and tests. As far as the writer knows, these were the first large alternators which were deliberately short-circuited at their terminals when running at full speed and at normal field charge. There were no instruments available to measure the first current rush, but it was obvious that this current was far greater than the steady short-circuit current of the machine under similar field charge, for there were ample evidences of a terrible shock at the moment of short-circuit. It was suspected at that time that the first rush of current was only limited by the armature impedance, and not by the so-called synchronous impedance which fixes the value of the steady short circuit current.

This also was the earliest machine of which the writer predetermined the field form and wave form by analysis of the flux distribution. Later, when making shop tests on one of these machines, the e.m.f. wave form was measured directly by rotating the field at normal field charge at such an extremely low speed that a voltmeter connected across the armature terminals showed such gradual variations in e.m.f. that readings taken at regular intervals could be plotted to form the voltage wave. Slow rotation was obtained by means of a steel cable wrapped about the outside of the external field and with one end of the cable attached to a small diameter spindle around which it was wrapped at a very slow rate. This was a very crude method, but the wave form thus abtained checked very accurately with tests made some years later.

Also, the early Niagara machines embodied one of the first distinct attempts to ventilate alternators artificially. Early belted machines had had small ven-

tilating bells on each end. But these Niagara machines were designed primarily with a view to setting up an abnormal air circulation by means of special "scoops" or ventilators on the umbrella supports. Very much thought and discussion were given to this subject of artificial ventilation. The results of our tests led to the arrangement of thte scoops so that they acted as exhaust pipes.

Also, water cooling of the armature spider was tried on some of these early machines, but proved ineffective, due to the fact that the cooling medium was applied too far away from the point of development of the larger part of the armature iron and copper losses.

INFLUENCE OF DIRECT-CURRENT DESIGN

It must be kept in mind that the general trend of direct-current development had a certain influence on alternating-current generator work. For example, there had been a slow, but positive tendency in direct-current generators, toward the engine type construction. Also, from 1890 to 1893, direct-current generator armature construction had changed from the surface wound to the slotted type. This doubtless had some influence in changing alternator design toward the slotted type, especially when the polyphase type of windings came into use. Also, there was a pronounced tendency toward the engine type, slow speed alternator, accompanying direct-current practice. Practically all of these early engine type alternators, except the inductor type, had rotating armatures. Meanwhile, an interesting development took place in the armature construction of some of these machines. In most of the smaller belted machines, open armature slots were used with machine-wound armature coils. However, many of the early larger machines, especially of the engine type, were built for relatively low voltage, such as 440 volts, two or three phase. This admitted in many cases of simple bar windings with one or two conductors per slot. This allowed partially closed armature slots with shoved-through straight conductors, and bolted-on end windings, giving a very strong substantial type of winding for resisting the rotational stresses. The partially closed slot became a sort of standard in Westinghouse machines, and endured for a number of years, and was even carried into the stationary armature type of machine when rotating fields came into general use. This partially closed slot arrangement was a very good one as long as the generator voltages were relatively low. The same may be said of the rotating type of armature as a whole. However, when high voltages came into more general use, a different construction was preferable.

In reviewing the period of the rotating armature, slotted types of machines, the monocyclic system should be briefly described. Apparently this was gotten out with the idea that it avoided the patented features of the Tesla polyphase system. The armature circuits on this monocyclic system were so arranged that, when carrying load, one phase carried nearly all of the energy load, while both phases supplied magnetizing current for the operation of induction motors. During the period when this machine was in vogue, single-phase lighting work represented the principal service, while induction motor loads were relatively small. With increased use of polyphase loads, and with the elimination of the patent situation, the monocyclic system gradually dropped out.

It was early recognized that a stationary armature winding would be an ideal one in some respects, but it was thought that any rotating field construction was bound to be a difficult and expensive one. The inductor type construction was supposed by some engineers to overcome the objections to the rotating field, but many others considered that this type was not a final one, as it did not use the magnetic material in the machine to the best advantage. In the earlier alternators, with insufficient ventilation through the armature core, relatively low magnetic densities were necessary to avoid excessive iron heating, and the inductor alternator, with its non-reversal of armature flux, was worked at almost double the induction of the rotating armature type of machine, and thus the disadvantages of the non-reversal of flux of the inductor type were masked. In other words, the inductor alternator was worked well up toward saturation, while the other types were worked at only about half saturation. However, with improvements in ventilation due to radial ventilating ducts, improvements in iron by better annealing and painting of the laminations, etc., the flux densities in the rotating armature machines were gradually increased until high densities, approaching saturation, were reached. A corresponding increase in flux densities in the inductor type was not possible, on account of saturation. Therefore the rotating armature type of machine, in the later designs, was much more economical than the inductor type, although the latter had a very considerable advantage, especially at high voltages, in its stationary armature construction. Due to the merits of the stationary armature construction, the present rotating field type of machine was gradually evolved, which possesses the advantages of the stationary armature of the inductor type machine and the reversing flux of the rotating armature alternator. It was the development of this type of machine which sounded the death-knell of the inductor type. However, the Westinghouse Company, about 1897, decided to bring out a line of inductor type alternators to meet market conditions, although such decision was contrary to the recommendations of the designing engineers of the company, whose recommendation in particular was in favor of the rotating field construction as a more permanent type. However, as the rotating field type was not yet established, except in a very minor way, and as the inductor type had been on the market for years, it was decided to build the inductor type, although the design adopted was somewhat different from the Stanley type. Three sizes of these machines were built, two belted and one engine

type, but the inductor type, as a commercial proposition, soon died out.

One of the interesting peculiarities of the inductor type alternator, as usually built, was in the enormous stray field appearing in the shaft, bearings, bedplate, and sometimes in the engine-governing mechanism in engine type units, necessitating in at least one case, the use of brass governor balls. In the usual construction of inductor alternator, there was but one exciting winding. The magnetic circuit and the field winding were arranged as in Fig. 8, which show both the Stanley and the Westinghouse constructions. The normal or useful path of the magnetic flux is indicated by the dotted lines *a, a*. Obviously, the field coil which set up flux through these paths could also send magnetic fluxes through the shaft, bearings and bedplate along the dotted lines *b, b*. Moreover, if the two bearings were not connected by a magnetic bedplate, as might be the case in engine type machines, then, in two-crank engines the engine cylinders and other parts became opposite poles of a very powerful electro-magnet, when the field coil was excited. The

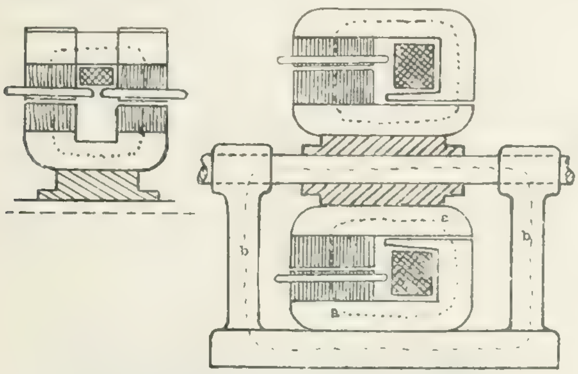

FIG. 8—SKETCH OF MAGNETIC CIRCUIT OF AN INDUCTOR ALTERNATOR

stray magnetic field set up in engine type units was sometimes so strong as to interfere with the governing mechanism. Also, with a strong undirectional flux between the bearings and shaft, each bearing became part of a small unipolar generator, of which the bearing surfaces formed the brushes. In some machines, quite heavy currents were generated in the bearings, sufficient to "eat away" the bearing surfaces or to pit them so that bad bearing operation resulted. As this was primarily a magnetic trouble, insulating the bearings from their pedestals would not stop the action. To overcome this trouble, the Stanley Company added a "bucking" coil placed around the shaft at one side of the generator, this coil being in series with the main field winding and magnetizing in the opposite direction. The ampere-turns of this bucking coil being made equal to those of the field coil, the resultant ampere-turns between the two bearings would be zero. Obviously, in an alternator with a bedplate and two bearings in which the armature frame rested directly on the bedplate, a single bucking coil at one side of the machine would not neutralize the stray field through both bearings.

ROTATING FIELD GENERATORS

Considering next the rotating field type of machines, possibly the earliest example was the Niagara type, mentioned before. This had an internal stationary armature, with windings on its outer periphery like the ordinary rotating armature. Outside this was the rotating field, consisting of a heavy forged steel ring with inwardly projecting poles. However, this type of construction was relatively expensive, and was never adopted generally. The more modern rotating field type of alternator, with external stationary armature, was a rather gradual development and, during this period, there was much heated discussion as to the relative advantages of the rotating field and rotating armature types. The rotating field gradually superseded the rotating armature construction for a number of reasons, the principal one having to do with the armature windings and voltages. In the rotating armature, the end windings were more difficult to support than in the stationary armature. Also, with the gradual advent of higher voltages, the stationary winding proved to be far superior. However, as a goodly proportion of the alternators built during this transition period were of the engine type and for low voltage, in which heavy bar windings could be used, (such being conditions under which the rotating armature made its best showing,) this type persisted for several years after the rotating field type became commercial. Gradually increasing voltages, however, necessitated the use of stationary armature machines, for at least part of the business. The manufacture of two types of apparatus for the same general purpose could not persist, and eventually that type was adopted exclusively, which allowed both high and low voltages. By 1900, the rotating field alternator had come into very general use, and the rotating armature type was disappearing. This rotating field type has persisted until the present time, although many minor modifications have been brought out from time to time, due largely to change in speed conditions, etc.

In the rotating field development, the tendency for a number of years was strongly toward the engine type construction and relatively low speeds in many cases. The construction was carried to the extreme, in some cases, where the usual flywheel capacity required for the slow speed engines was incorporated in the field structure of the alternator itself. In some cases, this meant enormously large machines for the output. A prominent example of this is found in the seventeen 6 000 kilowatt engine-type machines designed in 1899 and 1901 respectively, and installed in the Fifty-ninth and Seventy-fourth street power stations of the Interboro Rapid Transit Company of New York City. As an indication of the changes taking place in the electrical field, it may be stated here that arrangements have been made recently to take out a number of these machines and install in their place 30 000 kw turbo-generator units. The exist-

ing engine type machines are probably in as good condition now as when first installed, and are being replaced simply because they occupy too much space in proportion to their output.

The rotating field alternator of the early days was not radically different from the rotating field alternator of today, the principal differences being in the type of armature windings, methods of ventilation, etc.

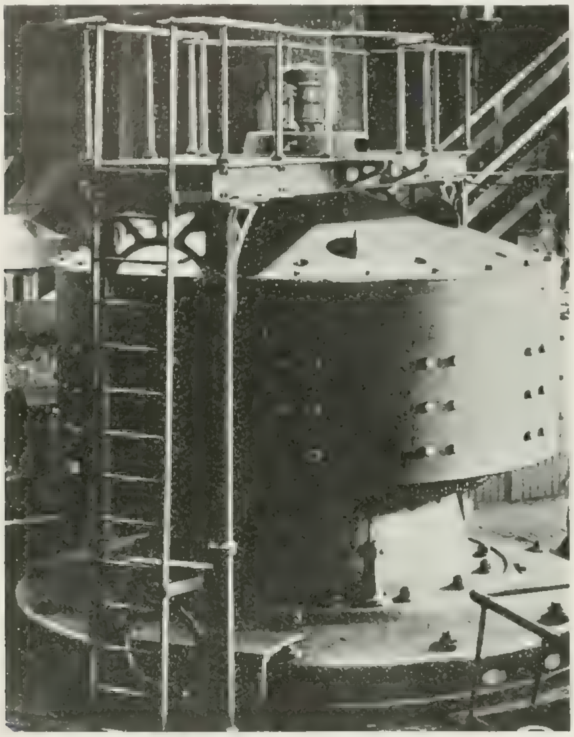

FIG. 9—SHOP VIEW OF 5 000 HORSE-POWER TWO-PHASE NIAGARA ALTERNATOR

FIELD CONSTRUCTION

In the types of field windings there has been but little change. In many of the old stationary field machines of large capacity, the field windings consisted of strap wound on edge, one layer deep. For smaller machines, either square or round wire was commonly used In the later rotating field machines, similar constructions are used. In the construction of the field itself, there have been some variations and modifications. In many of the older machines the poles were laminated as at present. The method of attaching the poles varied in different constructions. In many of the earlier Westinghouse rotating fields the laminations were punched with two or more poles in one piece, the poles having no overhanging tips, and the field coils being held in place by metal wedges between pole tips, fitted into notches or grooves at the pole tips, each pole being attached to the field ring or yoke by means of bolts or dove-tails. This latter construction possesses numerous advantages, in that cheap dies can be used, and the same pole punchings can be used for a number of different designs, in which either the diameter or the number of poles is varied.

WATER WHEEL TYPE GENERATORS

With the advent of the turbo-generator on a large scale, the engine type rotating field alternator almost disappeared from the manufacturing field, except in the smaller size units. However, during this period there has been a gradual development in the use of water powers, and water-wheel driven generators have come into much greater prominence in the past few years. In this line of development, speeds and capacities, unheard of in the earlier days, have become accepted practice with the development of both high-head and low-head water powers. In the former the tendency has been toward very high speeds for a given capacity such as the 17 000 k.v.a., 375 r.p.m., Westinghouse machines, built for the Pacific Light & Power Company, and the 10 000 k.v.a., 600 r.p.m., Westinghouse generators, built for the Sao Paulo plant in Brazil. Typical examples of low-head, slow-speed practice are found in the 60 cycle, 75 r.p.m., 96 pole, 2 700 k.v.a. Westinghouse generators for the Stevens Creek development, and the 25 cycle, 58 r.p.m., 52 pole, 9 000 k.v.a. General Electric generators for the Keokuk plant. The former are abnormal in the very large number of poles required for moderate output, while the latter are abnormal in the very low speed. Both of the above machines are of the vertical type, and are examples of a very pronounced tendency toward vertical machines, which has been apparent in the later water wheel practice.

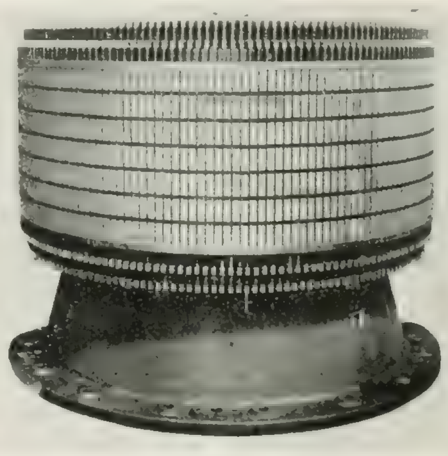

FIG. 10—STATOR OR ARMATURE OF NIAGARA ALTERNATOR

On account of the high speeds of some of the modern rotating field alternators, mechanically stronger spiders have come into general use. Even in moderate speed units the usual high runaway overspeed of 100 percent has necessitated the use of very substantial spiders.

(*To be continued*)

Purchased Power and Bituminous Coal Mining

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PURCHASED power affords so many advantages to the majority of bituminous coal operators that it will probably be only a question of time until most of them will be using it. In the meantime the coal operators must become acquainted with the merits of central station power, and the power companies must first learn how power is used to produce coal economically, and what advantages their service offers over power plants at the mines operated by the coal producer.

THE PRESENT SITUATION

The situation before the average coal operator is such that purchased power will supply a means to assist in solving some of his most difficult problems. These are:—

1—How to increase the production.

2—How to reduce the cost of mining.

3—How to keep the increase in the investment consistent with the increase in production.

Many operators realize that electricity applied to their mines will enable them to increase their output, but are holding off because of the investment required to equip a mine electrically and install generating apparatus. A mine now using steam power and mule haulage can change to electric power at a minimum expense if the electricity is purchased from a power company, since, by so doing, the greatest item of expense (the power plant) is eliminated. In this manner the tonnage can be increased with but a small increase in the capital account. With an isolated plant, the increase in the demand for power per ton of coal mined, as the underground workings are extended, frequently requires expensive alterations and additions in the power house. When central station service is used, additional power can be secured at any time.

The power required by the average mine today is three times greater than the amount necessary ten years ago. With the growing demand for coal from individual workings, the cost to produce it has become greater and the capital necessary has increased still more largely, so that it is becoming increasingly difficult to finance increases or alterations in mine power plants. By purchasing power the tonnage can be increased, the production costs reduced and extensions can be made at a minimum expense. The idea of an isolated power plant is so firmly rooted in the average operator's mind, however, that he must first become acquainted with the possibilities of purchased power.

POWER

Power is used in bituminous mines to operate pumps, fans, hoists, haulage and gathering locomotives, gathering reels, coal cutting machines and punchers. A general plan cannot be laid out that will apply to the electrification of all mines. Each type presents problem in itself and must be specially treated as needed to cover its own peculiar conditions. The following is a general outline of the applications most commonly used.

Small pumps are driven by 250 or 500 volt direct-current motors. They are frequently operated only during the day, and the power supply is taken from the nearest trolley or cutting lines. Larger pumps in many cases are operated only at night, or are operated continuously, and are commonly driven by 2 300 volt alternating-current motors. The fans operate continuously and are also driven by 2 300 volt alternating-current motors. The principal advantage of this application for the large pumps and fans is that it allows the use of a smaller motor-generator set, the losses incurred in transforming alternating to direct current are eliminated, the motor-generator sets may be operated only during the day or at such times as the mines are in operation, and the total capital expenditure is much less. Haulage and gathering locomotives, gathering reels, coal-cutting machines and punchers are driven either by 250 or 550 volt direct-current motors.

OLD METHODS

The methods used in the early days to mine coal were very primitive. The operation generally consisted of digging a hole in the side of a hill at the outcrop. The coal was undermined with a pick and then forced down with wedges. It was then loaded into small cars running upon wooden rails, and after which the cars were pushed out to the surface by men. As the distances from the surface became greater the work of pushing the cars in and out became quite burdensome. Mules were then initiated into the mysteries of underground haulage. This faithful animal has become so firmly rooted in this occupation that it will be some time before he has become completely supplanted by more economical methods of haulage.

PUMPS

The first power required in the early mines was for the water pumps. Unless the entries could be so driven that the mine was self-draining, more or less water would accumulate in the workings, which had to be pumped out to keep the mine in operation. This pumping was at first, and is still, largely accomplished by steam pumps, mostly of the reciprocating type. The steam is generated in a boiler plant located near the pit mouth and then carried underground to the pumps, through steam lines, which are frequently of considerable length. In the hard coal region it is a

common experience to see a steam line carried over the surface of the ground for several thousand feet from the boiler plant and then disappear down a bore hole several hundred feet to a pump. Only very poor economy can be obtained under such conditions due to the large amount of condensation, drop in steam pressure and leaks. The reciprocating type of pump taking steam at full stroke is also inherently uneconomical in the use of steam. They often consume 120 to 130 pounds of steam per horsepower hour.

Compressed air is also used to quite a large extent in operating pumps. The disadvantage of this system is that it requires considerable compressor capacity; also it is not as economical as steam although it has the advantage of no condensation.

In the better class of mines the steam and the air pumps are being replaced by electrically driven pumps, thus effecting a considerable saving in the upkeep of the pumps and in the power consumption. The losses in electric systems are comparatively low and the maintenance can be kept low with very little attention.

For small pumps up to 25 horse-power, direct-current motors, geared to duplex or triplex pumps, are generally used because the source of power for them is taken from the nearest haulage or cutting lines. These motors are usually arranged for self-starting and require very little attention. The larger pumps are generally of the centrifugal type and it is the common practice to drive them with alternating-current motors. The practice in some of the large mines is to operate several small reciprocating pumps throughout the mine during the day, pumping into a common sump. The sump is then pumped out at night with large centrifugal pumps, this arrangement improving the load-factor to a considerable extent.

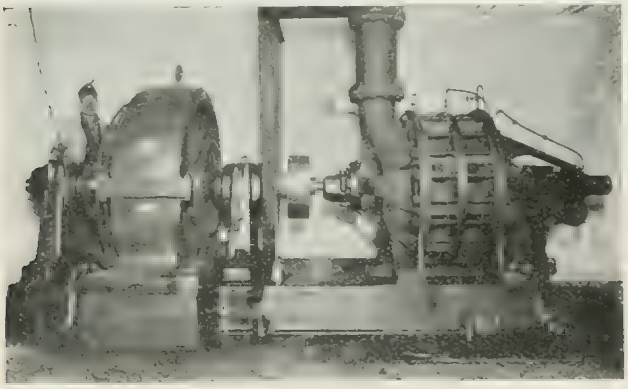

FIG. 1—MOTOR-OPERATED CENTRIFUGAL MINE PUMP

VENTILATING SYSTEMS

The next department about the mine to require power was the ventilating system. In the early days the operators depended entirely upon natural draft or furnaces. Now a forced or induced draft produced by a power-driven fan has become the most reliable method of ventilation. A large percentage of these fans are driven by steam engines; however, the steam lines are often long and frequently uncovered, so that the steam losses are high.

Owing to the importance of the fan operation, any new method of drive must prove itself reliable before mine operators consent to its use. The electric motor has proven itself most reliable and dependable when applied to a mine fan. It has many advantages over the steam engine as it requires less attention, less repairs, consumes less power and the continuity of operation is more assured.

In applying an electric motor to a mine fan it is seldom possible to use a direct-connected motor owing to the inherent low speed of the mine fan. Belting, gearing and chain drives are the methods generally used, belting being the most satisfactory when the reduction is not too great. Both alternating and direct-current motors are used, the advantages being with the alternating current motor when purchasing electricity, as no transformation is necessary; also with this arrangement the direct-current power equipment can be shut down during a portion of the 24 hours. In some mines the fans are operated at the same speed 24 hours per day, while in others, they are run full speed during the day and at one half speed during the night, on Sundays and holidays. In this way considerable power can be saved. The method used depends upon the locality, and the amount of gas in the mines.

FIG. 2—STEAM DRIVEN FAN CHANGED OVER TO MOTOR DRIVE

When direct-current motors are used for this work they are usually of the shunt type. By using commutating poles a considerable variation in speed can be obtained by field control at high economy. For constant speed fans driven by alternating-current motors, the squirrel-cage type is used. When two speeds are desired, a double-winding squirrel-cage motor is satisfactory. If a variation in speed is required, a wound-secondary motor must be used with resistance inserted in the secondary circuit to reduce the speed. With this application the economy at low speed is of course low, but as the power to drive a fan varies about as the cube of the speed, the actual power lost is not large at greatly reduced speeds. The motor and control for a mine fan should be as simple and reliable as possible. A properly installed motor-driven

fan will operate over long periods of time with practically no attention, beyond an occasional inspection.

HAULAGE

As coal mines became better developed and the length of the haul increased, it soon become evident that some mechanical method of haulage must supercede the animal haulage, since the expense increased very rapidly, as the length of the haul became greater. Rope haulage was first tried, the rope being driven by a steam engine. There are many conditions today

FIG. 3.—THE OLD AND THE NEW METHOD OF MINE HAULAGE

where the rope provides the best system of haulage. For the majority of conditions, however, the electric locomotive has proven the most economical and efficient method for both haulage and gathering. Our old friend the mule has been driven from the main haulage in the larger mines for some time and is now making his last stand at the gathering. The average period of service of mine mules is not over four years. The cost for feed, harness, veterinary services and stabling will average 50 cents per day. Adding the cost of the drivers to this, it is not difficult to show a considerable saving by the use of locomotives.

In extremely gaseous mines, compressed air locomotives are sometimes used to advantage. This type

FIG. 4—TANDEM UNIT MINE LOCOMOTIVE

of locomotive should be used only when it is impossible to use the trolley type. Its cost of upkeep is very high. The storage battery locomotive, properly constructed and equipped, will probably be the solution for the gaseous mine. At present its high first cost is a little discouraging.

As mine haulage is in many respects similar to a railway system, the electric locomotive is equipped with much the same type of motor and control. In this country, direct current at 250 or 550 volts is the universal practice. The motors are series wound and in the later types are equipped with commutating poles, which greatly increase the reliability of the motor. This feature, to a large degree, also reduces the cost of motor repairs and consequent delays. The controller is of the drum type arranged for series and parallel operation.

Most locomotives are equipped with two motors, although three motors are sometimes used on large locomotives. Where a heavier locomotive is required than the rails can carry, two locomotives are coupled

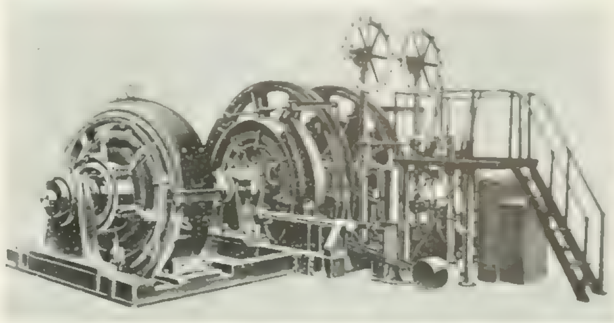

FIG. 5—REEL HOIST BUILT FOR TH[illegible] MINING COMPANY

together and operated in tandem from one controller as shown in Fig. 4.

Gasoline locomotives are being tried for main haulage but so far have met with indifferent success.

GATHERING

For gathering service two types of reels are used for collecting the cars from the rooms to which the trolley wires have not been extended. The cable reel consists of a single or double conductor cable wound upon a small drum and so arranged that a tension is kept on the cable at all times. This cable supplies power to the locomotive and unwinds and winds up

FIG. 6—SULLIVAN AIR PUNCHER IN USE

as the locomotive moves in or out of the room. The traction reel consists of a small motor-driven winch mounted on one end of the locomotive, and is used to haul cars out of rooms where it is not convenient to use an electric cable reel. This type of reel is best

suited to mines where the rooms are worked to the dip and the grades are too severe for locomotives.

For gathering service locomotives ranging from 3.5 to 8 tons are used while for main haulage the weights run from 6 to 20 tons.

ROPE HAULAGE AND HOISTS

The rope haulage system, previously mentioned, is used on grades ranging from 0 to 90 degrees. In practically all cases they were first operated by steam, although quite a number of gravity systems are in use. Where power is purchased or the hoisting outfit is located some distance from the steam plant, an electric motor is used. A large number of steam haulage systems and hoists have recently been changed from steam to electric drive. For small hoists and haulages, both alternating and direct-current motors are used, depending on local conditions and the kind of power available. For large haulage units or large hoists of slow or medium speed, the alternating-current wound secondary motor is used with a liquid or magnetic controller. For large high-speed hoists, a separately excited direct-current motor is used, taking power from a special motor-generator set, usually equipped with a heavy flywheel, to equalize sudden loads. A hoist of this type is illustrated in Fig. 5.

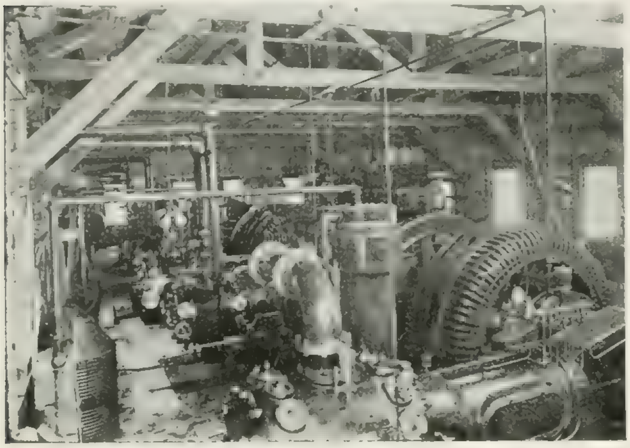

FIG. 7—MOTOR-DRIVEN AIR COMPRESSOR PLANT

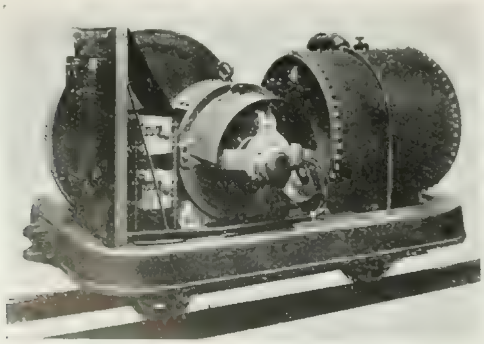

FIG. 8—PORTABLE MOTOR-DRIVEN COMPRESSOR

MINING COAL

The actual operation of mining coal consists in under-mining the coal at the floor and then shooting down the coal above by light charges of powder placed in holes drilled between the under-cut and the roof. As previously stated, in the early days before the use of powder became the practice, the coal was wedged down. This was a slow and very tedious process. The undermining was first accomplished by hand with ordinary mine picks. In fact a large part of the coal today is obtained by pick mining.

Among the simplest mechanical means for undercutting the coal is the compressed air puncher. It consists of a reciprocating chisel operated by air. The operator directs the reciprocating chisel against the coal and an assistant shovels back the fine coal produced, so as to leave a clear opening. This under-cut is about 16 inches high in front and four inches high at the rear and is cut back from four to five feet. This wedge shaped cut greatly assists in bringing the coal down with light powder charges without breaking it up too fine. Fig. 6, illustrates a machine of this type in operation.

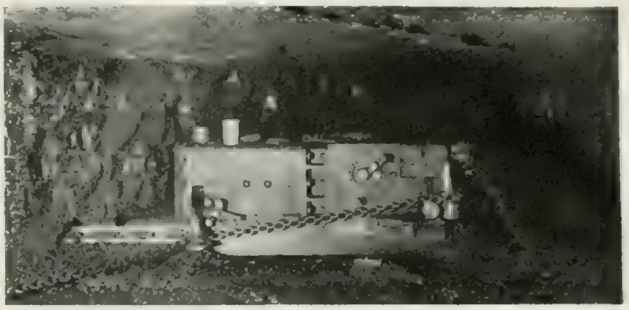

FIG. 9—SULLIVAN IRON CLAD CHAIN MACHINE CUTTING IN FRONT OF A SULPHUR BALL

The compressed air plant to furnish air for these punches is usually located outside the mine near the boiler plant. Motor-driven compressors are operated very successfully with purchased power. They furnish a steady load for a synchronous motor, which in turn can be used for power-factor correction. Whenever possible, the electric drive should be located in the mine because of the inefficiency of transmitting compressed air. Portable compressor plants are sometimes used to help out the main plant and keep up the pressure at the far end of some of the pipe lines. Such an outfit is illustrated in Fig. 8.

FIG. 10—RESULTS OF BLAST OF CUT MADE AS SHOWN IN FIG. 9

A combined electric and air puncher is in use which gives the advantage of electric transmission of the energy and pneumatic operation of the puncher. This really can be classed as an electric cutter, giving a wedge shaped under-cut which is not obtained with a chain machine.

A number of straight electric cutting machines are on the market and consist of moving chains which are mounted on a number of small picks or chisels. These machines make an under-cut of uniform thickness four to six inches thick and six to six and one-half feet deep. The short wall type of chain machine will cut into the face of the coal and then move across a 25 foot room in about ten minutes, while an air puncher will require about thirty minutes to do the same work. It is largely due to machines of the former type that the immense coal production of today is possible. The labor supply of today would be far from adequate if all coal were mined by the hand pick method. Fig. 9 illustrates an iron clad chain cutting machine making a cut across the face of a room; and Fig. 10 shows the results of blasting down the coal after having been undercut by the above machine.

The chain cutting machines are generally equipped with 30 horse-power direct-current compound-wound motors at 250 or 555 volts. Recently some of these machines have been driven successfully by alternating-current, squirrel-cage motors.

AUXILIARIES

There is often a considerable amount of power in use on the outside of a mine. This power consists principally of auxiliary hoists, chain haulage, crushers, shakers, elevators, washers, pumps, machine shop, etc. In many cases these auxiliaries are driven by individual steam engines, whose principal virtue is that they give fairly high continuity of operation. These auxiliaries can be easily taken care of in a much better and more economical way by substituting electric motors for the steam engines. In most cases alternating-current motors can be applied, which greatly simplifies the power system.

[illegible]

In mines not using electric power no attempt is made to light the outside workings. It has been found however, that some illumination is necessary at all switches, cross-overs, partings, pumps and underground fans. The incandescent electric lamp has proven the best and cheapest method of providing underground illumination.

CONCLUSION

It has been the experience of those mines which have changed over from steam to electricity, that a great saving has been effected and the output has been increased. Of course, after a mine has changed over, the operating force will require a little time to adjust themselves to the new condition. The saving and increase in the output by use of electric power, makes itself most manifest when power is purchased from a central station. The initial investment, and the worry and care attendant on the operation of a substation is very much less than with an isolated plant. This is so to such an extent that an operator once using purchased power will rarely, if ever, consider going back to his own power plant.

It is not an uncommon thing, when investigating the power conditions at a mine with an isolated plant, to find that the power generated per ton of output is as high as 12 to 14 kw-hr., with a corresponding cost for power running from 15 to 25 cents per ton. With the intelligent use of purchased power the consumption should not average higher than 2 to 5 kw-hr. per ton and the total cost for power should not average higher than 3 to 7 cents per ton of output. In changing over to central station power the greatest care should be exercised in selecting the proper power system and power equipment, to see that the particular arrangement is adopted which will give the best results under the conditions prevailing in the mine.

Experimental Temperature Measurements of Electrical Machines

O. W. A. OETTING

THE ORDINARY commercial method of measuring temperatures involves the use of mercury thermometers. Although this method is quite satisfactory for commercial testing and gives a good indication of the safe working temperatures of the apparatus, it makes it necessary for designers to go through extensive calculations to determine the actual temperatures at various points within the machine. For this reason, electrical thermometers have been used recently to obtain direct measurements of the temperatures within the machine for the purpose of determining the temperature gradients from the inside to the radiating surface, for design data.

Temperature rise always accompanies the expenditure of energy. Frictional forces, such as result when two surfaces rub on each other, cause a rise in temperature of the material which is subjected to this friction. During the operation of cutting or machining any material, the material becomes hotter, the rise in temperature depending upon the rate at which the work is being done. Similarly, in electrical machines, the temperatures of the various parts rise be-

cause energy is expended during the operation of the machine. Direct calculation of the temperature rise in such machines is an extremely involved problem; so designers must be guided by the actual measurement of the rises in the machines.

EFFECT OF TEMPERATURE

An electrical machine is made up essentially of iron, copper and insulation. The maximum allowable temperature affecting any of these materials is the factor that must be determined in the measurement of the temperatures of electrical machines.

The energy that causes the heating of electrical machines is that which is expended in the copper, due to the resistance of the windings; that which is expended in magnetizing the iron, due to its hysteresis; that which is due to eddy currents in the copper and the iron; and that which is due to the frictional losses, such as brush and bearing friction and windage. The amount of these losses is dependent upon the quality of the various materials that are used in the construction of the machine; hence the use of better grades of material, such as of steel and copper, will lower the losses in the machine, and consequently decrease the temperature rise, provided all other factors of the machine remain the same. Changes in the proportions of the material used will also produce decided changes in the temperature rise. The problem for the designer to decide, then, is the lowest cost of a machine that will not have a temperature rise great enough to interfere with its successful operation.

The principal question to be determined in the design of an electrical machine is the limiting temperature of any material used in its construction. This limiting temperature is that at which the insulation becomes damaged, rather than that determined by either the copper or the steel. It is evident, therefore, that the insulation is the vital part of the machine when the maximum allowable temperature is under consideration, and the temperatures of the iron and copper need only be determined in so far as they affect the temperature of the insulation.

For a full analysis of the temperature gradients of a machine, it is necessary to know the sources of heat and its distribution to the other parts of the machine. The temperature gradient in the field coils of a machine can be determined without a great deal of difficulty. In the armatures, however, the problem is much more complex. Here, there are two sources of heat; one is the copper, and the other the iron.

There are three paths along which the heat can flow from the copper to the air:—

1—Through the length of the copper conductor to the end windings, thence through the insulation to the air.
2—Through the insulation and the slot wedge to the air in the air gap.
3—Through the insulation to the laminations.

In armatures which have a comparatively narrow core and well ventilated end windings, there will be a relatively large flow of heat from the buried copper to the end windings. In a machine under full load, the copper will probably be at a higher temperature than the teeth of the armature; so some heat will flow from the copper to the laminations. If, however, the temperature of the copper is the same as or lower than that of the laminations, then the heat of the buried copper must flow along the other two paths. As a matter of fact, when a machine is running on no load or on a very light load, with practically no copper loss, there may be a considerable iron loss which will heat the laminations and cause heat to flow from them through the insulation to the copper and thence to the end windings.

In the armature iron, the problem is just as complicated. In this case the source of heat is in the armature teeth and in the laminations. The paths along which heat can flow from the laminations are:—

1—Along the laminations to the end of the tooth and into the air in the air gap.
2—Across the laminations of the tooth to the ventilating ducts.
3—Through the insulation to the copper and end windings.

METHODS

The method employed in taking the temperature, the time required in taking readings and also the conditions under which they are taken, may have quite an influence upon the readings obtained. In most cases, direct measurement of the temperature of the insulation in the hottest portion of the machine is practically impossible; in order to obtain reliable results of such temperatures, it is necessary to measure some adjacent temperatures and from these derive the desired results. The temperatures of the two faces of any of the insulation will be very nearly the same as that of the adjacent parts, and the temperature of the intervening insulation will be between these limits. For example, the insulation on an armature coil will have the local copper temperature on one side and the local iron temperature on the other side. One of these may be higher than the other depending upon the relative losses in the iron and the copper, the ventilation, and the heat conductivity of the adjacent paths of heat flow. If at all points throughout the length of the slot the iron is hotter than the copper, then the hottest point of the insulation can be determined by measuring the maximum temperature of the iron. If the copper at any point is hotter than the iron, it is fair to assume that the hottest coil insulation is next to the copper at the center of the slot. The only temperature measurement that can be taken is on the outside of the coil at the center of the slot, and to obtain the maximum temperature of the insulation it is necessary to allow for the temperature gradient through the insulation.

The accuracy of all tests will depend upon the measuring device, its nearness to the point to be measured, and a knowledge of the temperature gradient between the point measured and the point at which the temperature is desired. Obviously the ordinary methods of measuring temperatures give no exact indication of the distribution of the heat inside of an

electrical machine. Heretofore special methods of measuring temperatures have been considered impractical and almost impossible. Recent developments, however, show that internal temperatures of electrical machines can be readily obtained by these methods.

The Thermometer provides the most common method employed in measuring the temperatures of electrical machines. Its chief recommendations are its availability, simplicity and cheapness. Its usefulness is limited to the temperature measurement of the external parts of a machine. Consistent results can be obtained by this method, provided the conditions under which it is used remain the same, but wide variations in temperatures will be obtained by changing the location of the thermometers and the method of application to the part in question. Sluggishness is an inherent characteristic and must be kept in mind in any application of thermometers. Then, too, the method of applying the thermometers, whether the bulb is exposed to the ventilation or is covered, thus causing a hot spot, must be carefully observed.

In the stationary parts of electrical machines, all the thermometers may be located before the start of the test, and as the temperatures increase gradually, there is no special difficulty in the thermometers following the temperatures very closely. In the larger machines, the thermometers should be protected from the windage of the machine, or from drafts, by a small covering. This may be putty, clay, or felt. Putty is rather soft at working temperatures. Clay makes a very good holding medium when carefully put on, but experience in numerous tests has shown that more uniform temperature readings are obtained with felt. On a certain generator a thermometer covered with a felt pad registered 68 degrees C., whereas the actual temperature taken by means of a quick acting thermo-couple was 68.4 degrees C. On the same machine a thermometer covered by means of putty registered 61 degrees C., while the actual temperature was 63 degrees C. In another test, thermometers covered with putty, registered from five to eight degrees higher at a temperature of about 80 degrees C. than those covered with felt. These latter thermometers checked the actual temperature to within one-half of a degree. So the different methods of applying thermometers will give results that are in no manner comparable with each other.

A standard covering must be used to obtain even fair results of temperatures of electrical machines. On windings this covering may be a small sleeve, the bulb being exposed only on one side; the whole being tied to the coil with twine. On iron laminations a felt pad about one and one-half inches square glued to the surface seems to give the best results. This method also is satisfactory when used on the large copper conductors. The pad must not be too large as a hot spot may be created; neither must it interfere with the radiation of the machine. On smaller machines the liability to hot spots becomes much greater and either a very small ball of clay is to be preferred, or else the thermometers should be left bare.

The method of obtaining temperatures of rotating parts by thermometers presents quite a different problem. A very wide range of results may be obtained on account of variations due chiefly to the method of getting heat from the body, whose temperature is to be measured, to the bulb of the thermometer. The thermometer bulb can be so placed with respect to the copper in the coil, that the resistance in the heat conducting path of the bulb is much greater than is desirable. For instance, if a thermometer is simply laid on the coil whose temperature is to be measured, and covered with a little waste, and another thermometer is placed on the coil and provided with a seat made of tin foil, two different results will be obtained. Obviously, with a metal seat, a larger amount of heat in a given time can be conducted from the coil across the insulation and thence to the bulb, than would be the case without the metal seat. In a certain test it was observed that the thermometer provided with a metal seat reached this maximum temperature six minutes before one simply laid on the winding, both being protected from the air in the same manner. The difference in the temperature readings was eight degrees, the cooling of the machine being quite rapid.

It is quite clear, then, that wide variations in temperature results may be obtained by the use of thermometers as indicators. To obtain correct interpretations of such results, the time and method of application of the thermometers must be known.

Rise by Resistance—The rise by resistance method is applicable only to the windings of the machine. It seldom gives entirely reliable results, first, because the resistance rise is only an average result, not distinguishing the hot portions from the cold; and second, because there are difficulties in obtaining accurate readings of the hot resistance. For windings of high resistances, such as field coils, fairly good results may be obtained by this method. Although the resistance measurement does not represent the hottest portion of the coil, since there is a temperature gradient from the center of the coil to the outside surface, yet in most field coils this gradient will not be excessive; so that the average temperature, while below the maximum, will still be a close indication of the safety of the coil.

In the case of low resistance windings, the results obtained are far from satisfactory. In the first place, laboratory methods and apparatus are required to obtain results with any degree of accuracy. Variations of contact with temperature are continually entering in, offsetting the accuracy of even the most reliable measurements. The proper interpretation of measurements in this case is much more difficult than in the case of field coils of high resistance. With the winding of the machine passing through several zones of temperature, the average value of the temperature

is but a slight indication of what may be existing in the various parts. For instance, if the end windings of an armature are well ventilated, so that the temperature of part of the end copper is but little higher than that of the air, there may be a small portion of the coil buried in the core which is at a considerably higher temperature, and yet has but little influence on the total resistance of the winding. Again, a portion of the end windings may be so packed together and so completely covered by bands, that the relative temperature rise here is high, while the armature core and the buried copper are at relatively low temperatures.

Temperature results taken by the rise by resistance method on a certain revolving field generator may be cited to show that erroneous deductions can easily be made from the results of such a test. The rise by resistance measurements on various tests of this machine were consistent and seemed reasonable when compared with the thermometer temperatures, the maximum rise being 45 degrees C. However, on opening the windings of the machine it was found on several coils that the insulation surrounding the portion buried in the bottom of the slot had been heated to a much higher temperature than the results by the rise of resistance method indicated. So the construction of the machine also must be considered when interpreting the temperature results obtained by this method of measurement.

Resistance Exploring Coils—This method of measuring temperatures depends upon the fact that the resistance of most metals varies with the temperature of the material. The percentage change in resistance of pure metals with temperature is larger than the percentage change in the volume of gases, and over twenty times as great as the volume change in mercury. The mass of the wire used in making the coils and that of the body upon which it is wound should be small, or else the temperature of the resistance wire will lag behind any changing temperature which is being measured and thus lead to erroneous results.

There are several methods in use for measuring the resistance of such coils, all of which give results with a fair degree of accuracy. Special indicators have been devised to enable these measurements to be made directly with very few complications. Resistance coils of special forms are also manufactured to be inserted in a machine at any point where it is desired to measure the temperature. These coils are made with either three or four leads which connect to suitable binding posts on the indicators. The extra leads are compensating leads and are required because there is usually a considerable temperature gradient from the coil to the indicator; this gradient causes a variable resistance in the leads which must be corrected so as to measure only the change in resistance of the coil itself. The indicators have a variable resistance which is adjusted until the galvanometer reads zero, to obtain a reading of temperature. This variable resistance is adjusted and calibrated so that the temperature is read directly on the scale of the indicator. The apparatus is convenient for reading temperatures quickly and accurately.

One of the chief drawbacks of this method is the danger of damage to the small resistance coil. To obtain a coil of small size, such as must be used within the slot of an electric generator, a considerable amount of fine wire must be used to obtain the necessary resistance. This makes the exploring coil frail and is apt to cause breakage. All these coils must also be carefully adjusted and calibrated. Likewise, the same leads must always be used in conjunction with a certain exploring coil; so that if it is necessary to increase the length of the leads, the calibration of the instrument is changed, and the correct temperature cannot be obtained unless a new calibration of the coil is made. Another decided disadvantage of the compensating leads occurs when many temperatures are to be read at a distance on one indicator. Also quite serious discrepancies may be obtained in results when coils wound with nickel wire are used in electrical machines. A magnetic field changes the resistance of the nickel wire to such an extent that a difference of two degrees C. has been observed when the field of a machine was thrown on and off.

Thermo-Couples—Another convenient and accurate method of measuring temperatures is by means of thermo-couples. This method is used largely in the measurement of high temperatures where thermometers cannot be applied. However, it has not been applied to low temperature measurements to any great extent because until recently, there was no portable indicating instrument sensitive enough to give accurate results without troublesome corrections or special adjustments. The method was used as early as the year 1830 by Becquerel, but its application to the measurement of the internal temperatures of electrical machines is quite recent.

It is a well known fact that when a junction of two dissimilar metals is heated, an e.m.f. is set up, its value depending upon the materials that make up the junction and upon the temperature to which the couple is heated. In a circuit including several different junctions at different temperatures, the total e.m.f. is equal to their algebraic sum. This phenomenon has been utilized in the measurement of high temperatures, where ordinary means such as mercury thermometers, were out of the question. The well known platinum, platinum-rhodium couple is used extensively in pyrometers for obtaining temperatures of furnaces, etc., where high temperatures are employed. The thermo-couple, however, is of much value also for low temperature measurements.

Two methods may be used to measure the e.m.f. of a thermo-couple:—one, the galvanometric method; the other, the potentiometer method. In the galvanometric method, a galvanometer is connected in series with the couple and the current causing the galvanometer to deflect is observed. To obtain the e.m.f. it is

necessary to know the resistance of the circuit. If this resistance is constant for all temperatures, the e.m.f. will be proportional to the current; so the galvanometer can be calibrated either in millivolts, or else directly in degrees of temperature. Most of the adverse criticism against thermo-electric measurements is probably due to the use of this method of measuring the e.m.f. of the thermo-couple. There are only a very few materials that do not vary in resistance with a change in temperature. Then, too, the action of a high temperature continuously on the couple is likely to cause a permanent change in its resistance. To offset these variations in resistance, a galvanometer of high resistance is used; then a change in the resistance of the couple will have only a slight effect on the reading of the galvanometer. However, this reduces the sensitivity of the galvanometer and the temperature results cannot be read with such a high degree of accuracy. This trouble is avoided entirely in the potentiometer method.

In the potentiometer method, the e.m.f. is measured by opposing it to the drop along a slide wire of uniform resistance throughout its length, and adjusting the slide until the galvanomter in the circuit reads zero. This gives a reading of the voltage of the thermo-couple without having any current flowing in the thermo-electric circuit. Fig. 1 is a diagram of connections of a temperature indicator based on the potentiometer principle. It consists of two cells, one of them S being a standard cell, and the other B, an ordinary dry battery; two resistances R_s and R_v; a galvanometer G; a slide wire W; and contacts C and D. The current in the potentiometer circuit is adjusted by changing R_v with contact at C until the galvanometer shows no deflection. When this adjustment is made, there is one milli-volt drop per unit division of the scale on the slide wire W. To obtain the e.m.f. of the thermo-couple, D is depressed and the contact on W is adjusted until the galvanometer reads zero. The drop is then read on the slide W.

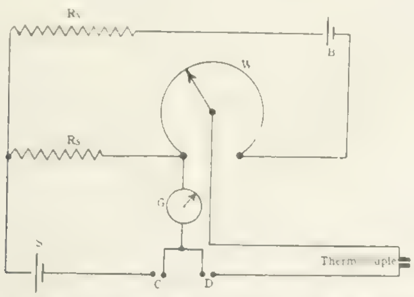

FIG. 1—DIAGRAM OF POTENTIOMETER CONNECTIONS

A diagram of another potentiometer method* is shown in Fig. 2, the standard cell being dispensed with in this indicator. This change was possible because the galvanometer used (a Paul unipivot) was sensitive enough to make the current adjustments in the potentiometer circuit. As a matter of fact the use of this galvanometer made it possible to read temperatures to an accuracy of about two-thirds of one degree C. in a range of one hundred and fifty degrees. The length of the potentiometer slide wire also was increased by winding seven and one-half turns of wire around a drum. This indicator was designed to be used with iron-advance thermo-couples, which have a linear calibration curve thatt is practically a straight line up to temperatures well above those obtained in electrical machines. The instrument was calibrated to read directly in degrees C.

In Fig. 2, B is an ordinary dry cell supplying a very feeble current to the potentiometer circuit made up of the potentiometer wire P, a variable resistance R_v and the resistance R. S is a special rocker switch with springs so made as to be connected between a and g on one side, and c and h on the other when neither side of the rocker switch is depressed. If the switch is depressed on side g, connection is made between g and b. This causes a current to flow in the circuit made up of the galvanometer G and the resistance R. The deflection on G gives a measure of

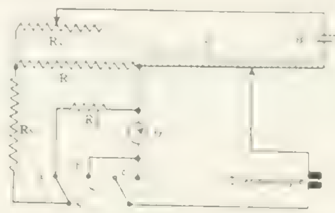

FIG. 2—MODIFIED DIAGRAM OF CONNECTIONS

the current in the potentiometer wire P. The resistance R and R_s are so adjusted and the galvanometer G is so calibrated that the current is at the proper value when the needle of the galvanometer reads the micro-volts per degree C. for the couple that is being used in the temperature measurement. With the current set at this value, the spring contact again connects a and g when the rocker switch is released. This connection substitutes R_g for the galvanometer G; and since R_g is made equal to the resistance of the galvanometer, the current in the potentiometer wire P remains unchanged. Now to obtain the temperature on the thermo-couple, the other side of the rocker switch is depressed, which connects d and h. This puts the couple, the galvanomter G, and a part of P in series (the couple being so connected that its e.m.f. opposes that of P). Contact K is run along the drum holding the potentiometer wire P until the galvanometer G reads zero. The result is read off on a scale along the wire P, which scale may be calibrated either in milli-volts, temperature or some arbitrary unit.

The great advantage of thermo-couples, like the exploring coils in the measurement of temperatures, lies in the fact that they record the actual temperatures of the body with which they are in contact and they can be applied where it is impossible to locate thermometers. In respect to the smallness of the

*This scheme has been used successfully for some time in research testing by Mr. L. W. Chubb, and recently has been adapted to commercial testing in the portable form described in this article.

measuring device, thermo-couples have an advantage over the resistance exploring coils, for the end of the thermo-couple is a very small element that may be placed at the exact point where the temperature is to be observed. The couples can be made to respond quite rapidly to changes of temperature by rolling the junction flat so as to present a large heat absorbing area and diminish conduction along the leads. Then, too, there is the possibility of placing the couple at any distance from the measuring device; the potentiometer is entirely independent of the resistance in this circuit, since no current flows in the circuit, and likewise of the length of leads from the couple to the indicator. When the temperature is read on the indicator, the galvanometer reads zero and no current flows in the circuit; so the resistance in this circuit has no effect on the reading. In the comparison of temperatures of electrical machines taken by thermo-couples and thermometers at the same spot, the results of the thermo-electric measurements invariably are the higher. This is due to the time lag of the thermometers, and may also be due to the lack of good contact of the thermometer on the body whose temperature is being observed.

This thermo-couple method of measuring temperatures was employed in testing a revolving field generator. Fig. 3 shows the various internal temperatures of both the core and the windings of the machine. Thirty-two thermo-couples were placed in the machine; sixteen in the core between the laminations in various positions, and the remaining sixteen on the coils within the slots of the machine. Leads from these different couples were brought out to a special switch and so arranged that any one of the couples could be placed on the measuring instrument and the temperature read. By this means, at least six different temperatures could be observed in one minute. It was possible to obtain temperature results at these thirty-two points of the machine, which, when plotted, showed the heating and cooling during the start and the shut-down of each run, and also the constant temperatures when the machine had reached its maximum temperature during the run. Fig. 3 gives a summary of this series of tests, showing seven of the principal temperature curves that were taken in these tests. In the maximum temperatures attained in these tests, it is possible to see the heat distribution throughout the machine as was mentioned previously under the effects of heating of machines.

Curves *A* and *B* of Fig. 3 show the heating and cooling of the machine during a normal field charge run. Of course it is reasonable to suppose that the laminations will become hotter than the coils in a test of this nature. It is seen that the copper temperature as indicated by couple No. *19* is slightly lower than that of the tooth laminations as shown by couple No *20* between the coil and the tooth, while the drop through the insulation and the wedge from the copper is 11 degrees, as shown by couple No. *17*. Thus no heat flows from the coil to the iron, but all is dissipated through the wedge into the air in the air-gap.

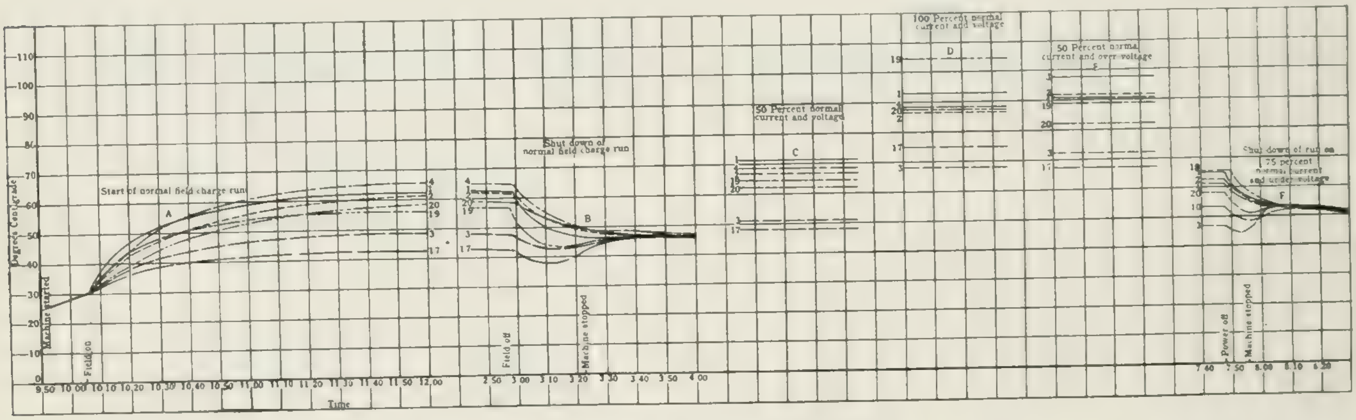

FIG. 3—SUMMARY OF SERIES OF TESTS

1—In iron ½ in. below top of tooth midway between air ducts. 2—In iron 1½ in. below bottom of slot midway between air ducts. 3—In iron ½ in. below bottom of slot next to air duct. 4—In iron 4 in. below bottom of slot midway between air ducts. 17—In slot between coil and wedge. 19—In slot between coils. 20—In slot between side of coil and iron.

When the field was removed on the shut-down of this test, there was no braking effect to stop the rotation of the machine except the friction of the bearings and the windage, and the friction of the brushes on the commutators of the two driving motors. It is interesting to note the various temperatures. Couple No. *17*, located between the coil and the wedge, cools until the rotation almost ceases; then it becomes warmer again, because the ventilation ceases and the hotter parts of the machine warm the air in the gap; this causes the temperature of the couple to rise. This effect can be noted, but to a lesser degree, on couple No. *3*, which is near an air duct in the iron.

Curves *C* to *E* of Fig. 3 show the maximum temperatures attained in several load tests. From the full-load curves, it is quite clearly seen that the hottest spot in the machine is in the coil in the middle of the machine. In a two layer coil, the temperature of the two layers must be almost the same. Therefore, a thermo-couple placed between the layers must find very nearly the copper temperature; because since there is no temperature gradient between the coils, there can be no heat flow between them. In this full

load test, it is observed that the copper temperatures are much higher than those of the iron, which is just the opposite effect to that which was observed in the iron loss test shown in *A*. Comparing the temperatures by means of the couples, it is seen that couple No. *19* is about 18 degrees hotter than couple No. *20*. But at the same time the temperature of No. *20* is much higher than it was in the normal field charge run. Since the iron losses in these two tests must be about the same, it naturally follows that the copper is heating the tooth laminations. In this full load test, the thermometers show a little less than the usual 40 degree rise, but the couples indicate almost double this rise within the machine. However, as thus is a mica insulated machine, the maximum temperature of 106 degrees C. is safe and allows a considerable margin for an overload before it reaches 125 degrees.

In each one of these tests it was possible to follow the heating and cooling of the thirty-two couples in the machine. These curves show the time when the maximum temperature is attained, and also indicate the equalization of the temperatures at the shutdown of the machine. This method of testing probably will never be used for commercial tests, but it gives excellent data in the experimental tests for the development of new machines. It also indicates the drop in temperatures of the machines before the rotating element comes to rest.

All the couples in the foregoing tests were placed on the stationary part of the machine. In another test thermo-couples were placed in the armature of a rotary converter and the leads brought out to slip rings. A considerable amount of trouble was experienced, due to the contact of the brushes on the rings, and the results were practically of no value. This scheme cannot be recommended in rotating elements. The number of couples that can be used is limited by the space available for the slip rings. The mechanical equipment required, especially on machines of high peripheral speed, makes the test extremely expensive, and the results obtained are questionable.

The Analysis of Periodic Waves

L. W. CHUBB

THE USUAL source of alternating-current and voltage is the alternator or inverted rotary converter, and the shape of the potential waves generated by them will depend upon the magnetic field form, the chording and general arrangement of the armature windings and the load conditions of the machine. A pure sine wave of potential is seldom generated and practically never in commercial circuits will there be such waves of voltage and current, because of cross currents with other machines and the distorting effects of transformers, line capacity, arc lamps, etc.

Often the distortions and variations from the sine shape are such that the conventional calculations cannot be used with accuracy and a more complete treatment of engineering problems by harmonic analysis is necessary. This article presents a new mechanical analyzer which has been in use for over a year and which works directly from a polar oscillogram of electric or sound waves.

In electrical engineering most problems, designs and conventional graphical diagrams dealing with alternating-current phenomena are now worked out upon the assumption of sinusoidal variations of potential, current, flux, etc. The sine wave shape in most cases gives the most satisfactory operation in alternating-current circuits, and the common calculations are also easier with the sine or simple harmonic waves as they allow graphical treatment by vector diagrams. Also, the currents, voltages, magnetic and electrostatic fluxes and forces which may be mutually induced or produced by sine waves in circuits and apparatus containing inductance, capacity and resistance are also waves of the same shape, because both the integral and differential of the sine function are cosine or quadrature sine waves.

THE FOURIER OR HARMONIC SERIES

Fourier was the first to show that any periodic function can be analyzed into a series of pure sine functions of the multiple angles. The waves of the alternating-current circuit are periodic functions, so that by this mathematical theorem we can resolve them, no matter how distorted, into a Fourier series or component sine waves of various frequency, amplitude and phase relation. Thus any wave of voltage or current may be expressed in the form:—

$$f(\Theta) = C_1 \sin(\Theta + \Phi_1) + C_2 \sin(2\Theta + \Phi_2) + C_3 \sin(3\Theta + \Phi_3) + \ldots C_n \sin(n\Theta + \Phi_n) + \ldots$$

If Θ is the time angle in electrical degrees, it is evident that the first term of the series represents a sine wave of maximum amplitude C_1, of fundamental frequency and displaced in phase by the angle Φ from the point $\Theta = 0$. Similarly each of the successive terms represents a multiple frequency wave or harmonic component of amplitude C_n, which is n times the fundamental frequency and which passes through zero, Φ_n fundamental electrical degrees from the point $\Theta = 0$.

It is difficult, in working problems with such polycylic waves to use the harmonic components in their various phase positions, and for this reason each

harmonic wave is usually resolved into two quadrature components (sine and cosine components). Thus equation (1) becomes:—

$$f(\Theta) = A_1 \sin \Theta + A_2 \sin 2\Theta + A_3 \sin 3\Theta + A_4 \sin 4\Theta + \text{------} + B_1 \cos \Theta + B_2 \cos 2\Theta + B_3 \cos 3\Theta + B_4 \cos 4\Theta + \text{-------} \quad (2)$$

This expression shows two distinct groups of waves, which are functions of the time angle, Θ. The sine terms represent one group of the harmonic component waves of maximum amplitude A_n, which cross zero at the point $\Theta = 0$. The cosine terms represent the other group, each of which has its maximum amplitude B_n, when $\Theta = 0$. The sign of the A coefficients determines which direction the sine wave passes through zero, and the sign of the B coefficients

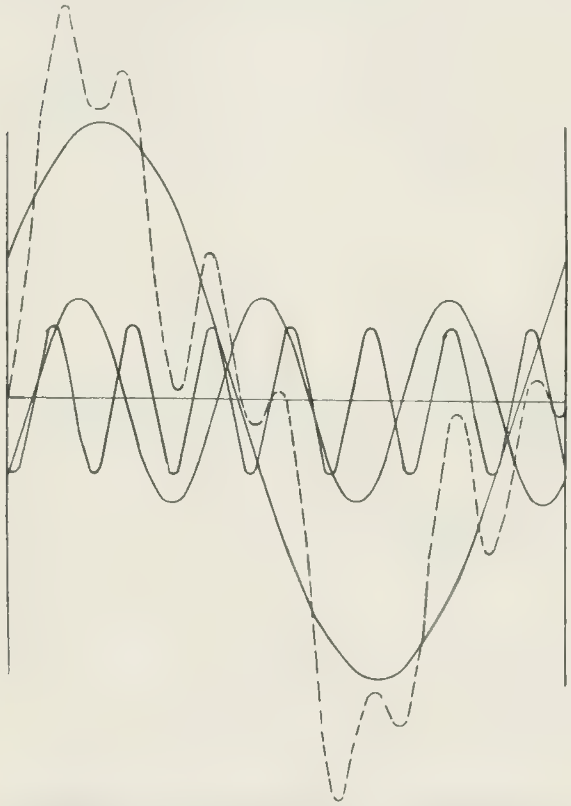

FIG. 1—PERIODIC WAVE RESOLVED INTO ITS FUNDAMENTAL AND THE THIRD AND FIFTH COMPONENTS

determines whether the cosine wave has a plus or minus maximum at $\Theta = 0$. These mathematical facts can readily be remembered because at the point of zero time the sign of the coefficient agrees with that of the amplitude in the case of the cosine or B *terms* and agrees with the sign of the slope or tangent of the curve in the case of the sine or A *terms*. It is evident that the coefficients C_n of equation (1) are the vector sum of the corresponding coefficients A_n and B_n in equation (2), according to the formula:—

$$C_n = \sqrt{A_n^2 + B_n^2}$$

Also in equation (1) the displacement of the n th harmonic, Φ_n in electrical degrees is:—

$$\Phi_n = \tan^{-1} \left(\frac{B_n}{A_n} \right)$$

The dotted curve of Fig. 1 shows a distorted periodic wave which is the sum of a fundamental, a third and seventh harmonic and can be expressed by the equation:—

$$X = 1.8 \sin (\Theta + 30^\circ) - 0.661 \sin 3 (\Theta + 15^\circ) - 0.50 \sin 7 (\Theta + 8^\circ 35')$$

The three component waves are also shown. The same curve shown dotted in Fig. 2 can also be expressed by the equation:—

$$X = 1.557 \sin \Theta + 0.467 \sin 3\Theta - 0.25 \sin 7\Theta + 0.9 \cos \Theta - 0.467 \cos 3\Theta - 0.433 \cos 7\Theta$$

and the six harmonics drawn show the three component waves resolved into the quadrature or sine and cosine components.

The point of reference or position of zero time in the expression of the Fourier series of any curve

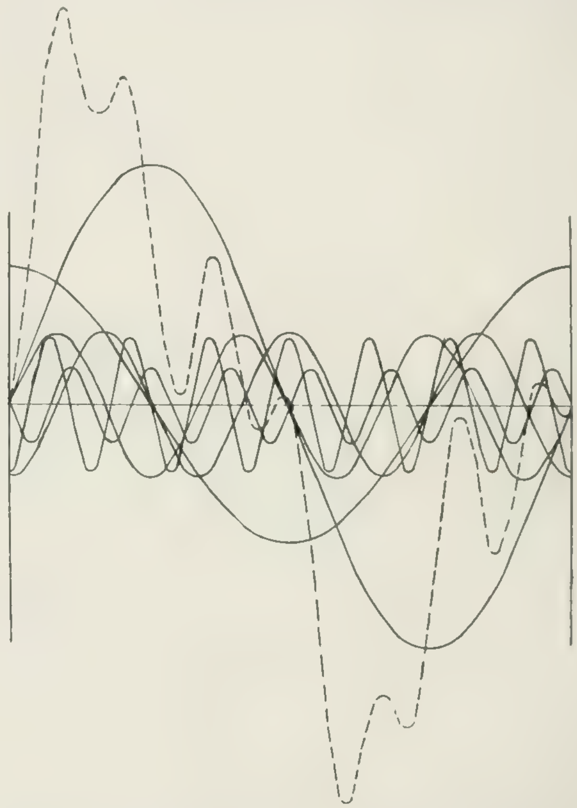

FIG. 2—SAME PERIODIC WAVE AS SHOWN IN FIG. 1
With the component waves resolved into the sine and cosine components.

is a matter of choice. Any shift of the time scale will change the values of coefficients in equation (2) and the values of Φ_n in equation (1). For a single curve it is usual to assume zero time ($\Theta = 0$) at the point where the curve goes through zero in the plus direction. Such a point of reference was chosen to express the equations of the dotted curve in Figs. 1 and 2.

It is usual to express the equations of two or more related curves in such a way that they refer to the same time axis. The lag or lead of currents is usually referred to the voltage and for this reason it is customary to select the point of zero time as the point where the voltage wave goes through zero in the plus direction and refer all waves of flux, current, voltage, etc., in the same system to this time axis of

electrical degrees. As an example Fig. 3 shows the voltage and exciting current of a transformer, both curves being referred to the same scale. On account of the agreement of these scales, calculations of the flux curve, the watt loss, etc., can readily be made. The Fourier series of the flux wave can easily be obtained by the simple integration of the equation of the voltage wave and if for example, the hysteresis loop is required, it can readily be plotted from the flux and current waves, which are in their proper time phase.

HARMONIC ANALYSIS

In the solution of problems for circuits having distorted wave shapes, a knowledge of the Fourier theorem will be of little value to the engineer, unless he is able to take the composite waves and analyze them into their component parts by evaluating the coefficients of the several terms of the general equation. The oscillographic wave record, or an assumed wave,

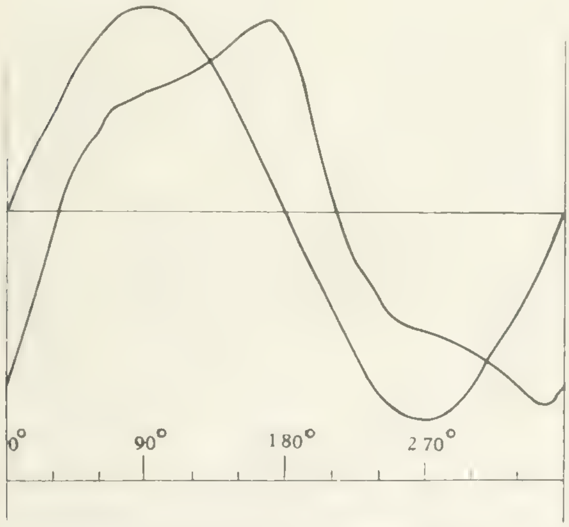

FIG. 3—VOLTAGE AND EXCITING CURRENT WAVE OF A TRANSFORMER

such as the field form of a motor, is the usual starting point for the analytic treatment of the periodic phenomena in electric circuits.

The ever increasing complications and variations in electrical circuits and apparatus make desirable a method of harmonic analysis which is quick, accurate, can easily be used by rule of thumb and without a working knowledge of the mathematics involved. It is important also to have a method which does not require replotting of the curve, the subdivision of the time axis or the measurement of any ordinates.

Several mathematical, graphical and mechanical schemes for harmonic analysis have been devised. The mathematical methods are too laborious to be practical even when tables and carefully arranged blank forms are used. Some graphical methods are very useful to extract the harmonics by groups, such as the third group consisting of the third, ninth, fifteenth and higher multiples of three. Graphical methods are, however, slow and inaccurate for a complete analysis and are not practical for waves containing high harmonics.

MECHANICAL ANALYZERS

Historical—The mechanical analyzers date back as far as 1876, when Prof. James Thomson[1] suggested a machine for analyzing the tide variations and later his brother, Lord Kelvin, perfected it. Some later machines are those of Prof. Henrici,[2] George Yule,[3] Geo. H. Rowe,[4] Michelson & Stratton.[5] These machines have not been used very extensively in electrical engineering because of their inconvenience or inaccuracies, the fact that they require the wave in question to be plotted to a certain scale in rectangular coördinates, that they require manual tracing or that they are not sufficiently positive in their operation.

New Analyzer—The new analyzer here described is adapted to work from a cut-out templet or grooved

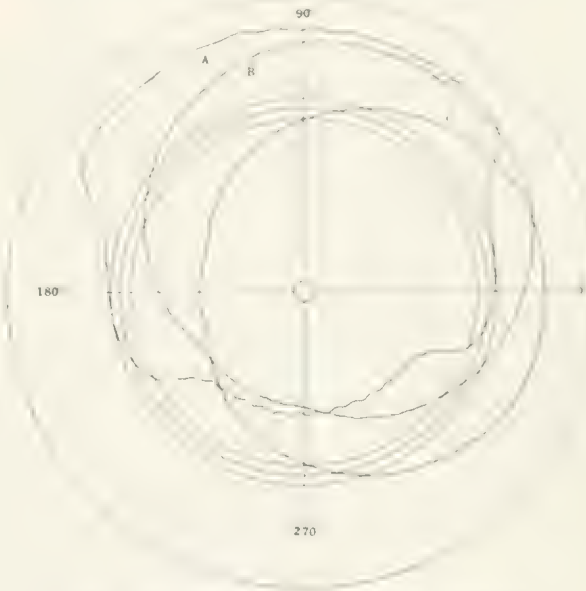

FIG. 4—POLAR OSCILLOGRAM OF AN ALTERNATOR
A—Field Form.
B & C—Voltage Waves.

record of a polar curve printed directly from a polar or circular oscillogram. Such an oscillogram is reproduced in Fig. 4, showing two voltage curves and the field form of a machine in their relative phase positions. The three concentric circles are zero lines for the three curves shown and the deflections are radially in and out from these lines. Such a picture has many advantages, but its use for harmonic analysis only will be treated in this article.

Fig. 5 shows the complete apparatus for analyzing any periodic wave quickly and accurately. It consists of a turntable T on which a cut-out template X of the oscillograph wave is secured. The turntable is mounted on a carriage C, which slides forward and backward on the rails RR, of the base. The oscillat-

(1)—Proceedings of the Royal Society, Vol. XXIV.
(2)—Phil. Mag., July 1894.
(3)—Phil. Mag., April 1896.
(4)—Electrical World, Mar. 25th, 1905.
(5)—Phil. Mag., Vol. XIV, p. 85.

ing motion of the carriage is produced by a crankpin *P* (Fig 6), on a worm gear *G* mounted in the base. The gear is driven by a worm mounted on the shaft *D*. The pin *P* runs in a transverse slot *S*, on the bottom of the carriage *C* and thus gives a simple harmonic motion to the carriage.

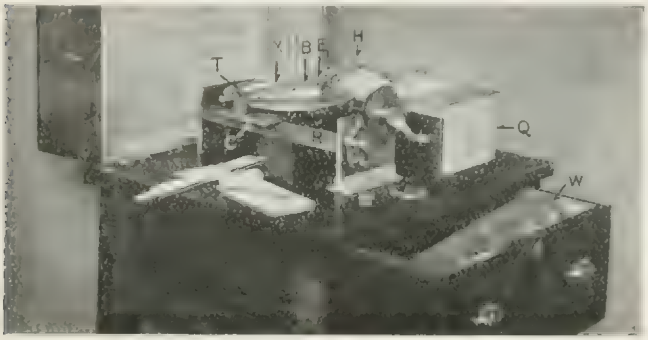

FIG. 5—MECHANICAL ANALYZER

The rotational motion of the turntable and template is produced through a worm wheel under the turntable and a worm which is mounted on the carriage and slides back and forth on the driving shaft *A*. As the template revolves, the cross-bar *B*, supported on the movable carriage, is given a transverse motion by the engagement of the contact point *E* with the edge of the template. The bar is pushed out by the template, and springs mounted on each side of the bar give the return motion and keep the contact point against the edge of the template. In the end of the bar is a jewel screw in which is placed the point of a polar planimeter *H*. The shafts *A* and *D* are driven by gears rigidly connected to the crank *K*. Gears *W* are provided to analyze for all even and odd harmonics from 1 to 50. The gear arrangement for the extraction of any harmonic is shown by the printed card *Q* (Fig. 5). In most cases only a single gear has to be changed to shift from one harmonic to the one of higher order.

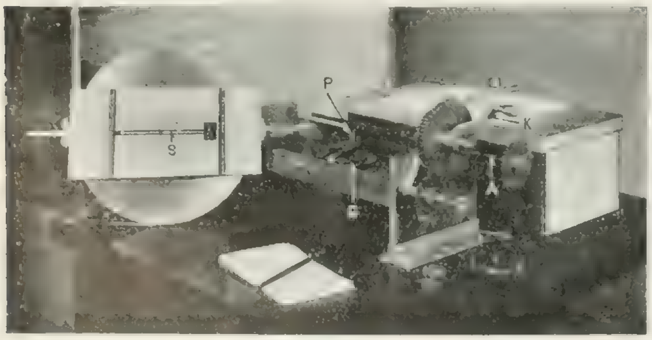

FIG. 6—[illegible]AL VIEW OF MECHANICAL ANALYZER

As the template revolves, the carriage oscillates and the end of the crossbar describes compound Lissajous figures consisting of a simple harmonic motion in one direction, and a transverse motion of the function to be analyzed.

Operation—The machine extracts the components one at a time and in any order desired. A complete analysis can be made in a few minutes by following a few simple directions and without any knowledge of the action of the machine.

The polar or circular oscillograph record is transferred with carbon paper or by photographic printing to a card of bristol board. From this a template is prepared by cutting around the curve to be analyzed. In the majority of cases only the odd harmonics of a curve need to be sought, as in alternating-current circuits the even harmonics of voltage, current and flux seldom exist, although arc lamps, mercury rectifiers, unsymmetrical machines (with an even number of pairs of poles), corona, etc., may introduce even harmonics.

A quick examination of the curve template in circular form will tell whether tests for even components, sine or cosine components may be omitted. If no even components are present the diameter of the

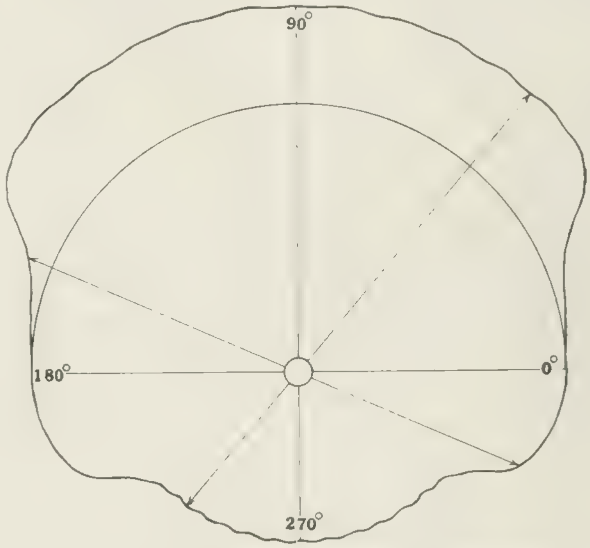

FIG. 7—CUT-OUT TEMPLATE OF POLAR OSCILLOGRAM

curve at all angles will be equal and equal to the diameter of the zero circle. If such a curve (Fig. 7) is symmetrical about the axis 90°—270°, it contains only sine or *A* terms. If the curve is symmetrical about the axis 0°—180°, the curve contains only cosine or *B* components. The field form template reproduced in Fig. 7 was found to have equal diameters and its symmetry about the axis 90°—270° shows that it is necessary to analyze only for the odd, sine components.

After thus determining which, if any, class of harmonics is absent, the template is clamped in place so that the point of reference ($\Theta = 0$) is at the contact point *E*, Figs. 5 and 8. The gears are arranged so that the carriage will make *n* complete oscillations while the turntable and template make a complete turn, *n* being the order of the harmonic component sought. The planimeter is set at zero and the crank turned until the turntable has made one revolution as indicated by a scale of degrees around the edge and a vernier index. The plainmeter integrates the area of the Lissajous figure described by its point and its reading

divided by a constant and n is the amplitude or coefficient of the harmonic component sought. The planimeter also indicates directly whether the coefficient is plus or minus.

The A or sine components are obtained when the carriage is started at the near end and the B or cosine components are obtained when the carriage begins in the center and starts toward the rear. The machine is arranged so that the shaft A can readily be thrown out of gear and the carriage independently adjusted to the proper starting position.

If S_a is the area indicated by the planimeter when the operation is started at the near end, then the exact value of the sine coefficient is:—

$$A_n = \frac{S_a}{\pi R n}$$

Where A_n = coefficient sought
π = 3.1416
R = Radius of crank pin (P, Fig. 6)
n = order of the harmonic

Similarly if S_b is the area indicated when the car-

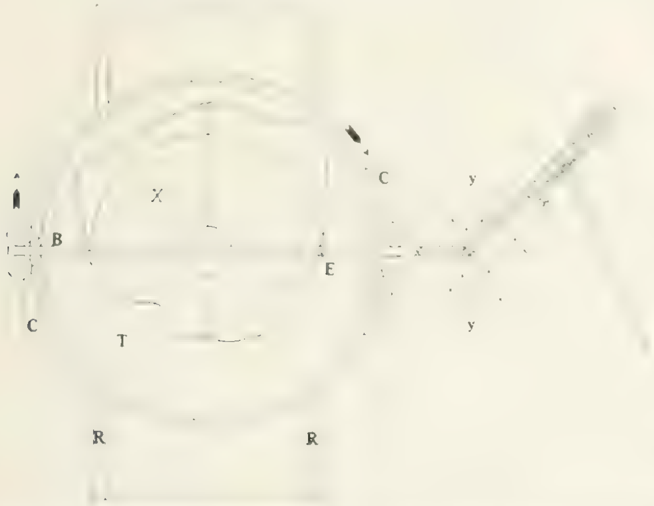

FIG. 7—ANALYZER SET TO DETERMINE THE COSINE COMPONENTS

riage is started in the center, the cosine coefficient is:—

$$B_n = \frac{S_b}{\pi R n}$$

If the planimeter reads square inches, R must be expressed in inches and the results for A_n and B_n will also be in inches. The values of A_n and B_n, multiplied by the calibration constant of the oscillograph will give the harmonic components directly in amperes or volts as the case may be. It is important to note that the planimeter indications are multiplied by n, and that although the amplitudes of the higher harmonics are usually small, the readings are exaggerated and can be accurately read from the instrument.

Mathematical Proof—In Fig. 8 let xx and yy represent the coördinate axes to which we are to refer the motions of the planimeter point. The relative position of the template, carriage, cross-bar, the point of the planimeter, and the coördinate axes are shown for the start and finish of the operation to extract the coefficient A_n.

As the crank (not shown) is turned, the template of the wave revolves with the turntable as indicated by the arrow. While it makes one revolution, the carriage makes n complete oscillations up and down. The end of the cross-bar generates a Lissajous figure as shown dotted, and the planimeter, which has its point in the end of the bar, integrates the area S_a of of this figure.

Let Θ = the angular position of the template expressed in radian measure.

R = the crank pin radius or half travel of the carriage.

x and y = the coördinates of the planimeter point with respect to the imaginary axes, xx and yy.

n = number of oscillations of carriage for one turn of the template (determined by the gear ratio).

S_a = the area of the Lissajous figure or motion of the point of the planimeter (read by the planimeter).

The transverse motion of the planimeter point is the funciton to be analyzed and can be expressed by the equation:—

$$x = f(\Theta) = A_1 \sin \Theta + A_2 \sin 2\Theta + A_3 \sin 3\Theta + \cdots + A_n \sin n\Theta + B_1 \cos \Theta + B_2 \cos 2\Theta + B_3 \cos 3\Theta + \cdots + B_n \cos n\Theta.$$

The vertical motion of the point, caused by the oscillatory motion of the carriage is expressed by the equation:—

$$y = R \sin \left(n\Theta - \frac{\pi}{2} \right) \qquad (4)$$

$$\text{or } y = - R \cos (n\Theta) \qquad (5)$$

From (5)

$$\frac{dy}{d\Theta} = n R \sin (n\Theta)$$

$$S_a = \int_0^{2\pi} x\, dy = \int_0^{2\pi} x\, n R \sin (n\Theta)\, d\Theta$$

When the value of x is substituted, the resulting terms of the form

$$(n R A_m) \int_0^{2\pi} \sin (m\Theta) \sin (n\Theta) d\Theta$$

are all zero except when m = n. Also all terms of the form

$$n R B_m \int_0^{2\pi} \cos (m\Theta) \sin (n\Theta)\, d\Theta$$

equal zero, and the equation reduces to:—

$$S_a = n R A_n \int_0^{2\pi} \sin^2 (n\Theta)\, d\Theta$$

$$S_a = n R A_n \pi$$

and transposed:—

$$A_n = \frac{S_a}{\pi R n} \qquad (6)$$

Fig. 9 shows the relative position of parts at the beginning and end of the operation to measure the coefficient B_n.

The transverse motion of the planimeter point is the same as before,

$$x = f(\Theta)$$

The vertical motion which in this case starts in the center (going up) is:—

$$y = R \sin (n\Theta) \qquad (7)$$

From (7),

$$\frac{dy}{d\Theta} = n R \cos (n\Theta)$$

The area (S_b) of the figure generated and integrated by the planimeter is:—

$$S_b = \int_0^{2\pi} x\, dy = \int_0^{2\pi} x n R \cos (n\Theta)\, d\Theta$$

In this case all terms of the form

$$n R A_m \int_0^{2\pi} \sin (m\Theta) \cos (n\Theta)\, d\Theta$$

are zero and all terms of the form

$$n R B_m \int_0^{2\pi} \cos (m\Theta) \cos (n\Theta)\, d\Theta$$

are zero except when $m = n$. The equation then reduces to:—

$$S_b = n R B_n \int_0^{2\pi} \cos^2 (n\theta) \, d\theta$$

$$S_b = n R B_n \pi$$

and:—

$$B_n = \frac{S_b}{\pi R n}$$

The dotted Lissajous figures shown in Figs. 8 and 9 indicate three oscillations of the carriage per cycle of the wave template and are therefore an illustration of the motions for the evaluation of the coefficients A_3 and B_3.

Curve Drawing.—It is sometimes desirable to have the harmonic components shown graphically, and after the analysis has been made the several waves can be drawn on a piece of paper or card placed on the planimeter table. To do this a pencil is placed in the end of the crossbar, a spiral template of steel is placed on the turntable (which gives uniform motion to the bar), and the amplitude and frequency are arranged by the adjustment of the crank pin radius and the gears, respectively. The phase relation of the component curves is arranged by the relative position of the carriage and turntable. The component curves of Figs. 1 and 2 were drawn in this way.

CONCLUSION

The accuracy and value of the machine in analytical work has been much beyond expectations, and it is now in daily use for a great variety of work. The double improvement in the method of taking oscillograms and analyzing the waves makes the harmonic study of periodic electric and sound phenomena commercial and profitable. Problems which take days to analyze by the former methods can now be worked out with greater accuracy in as many hours. On account of the laborious methods, the engineer has often avoided an harmonic analysis of electromagnetic disturbances, features of design, unusual noises in ma-

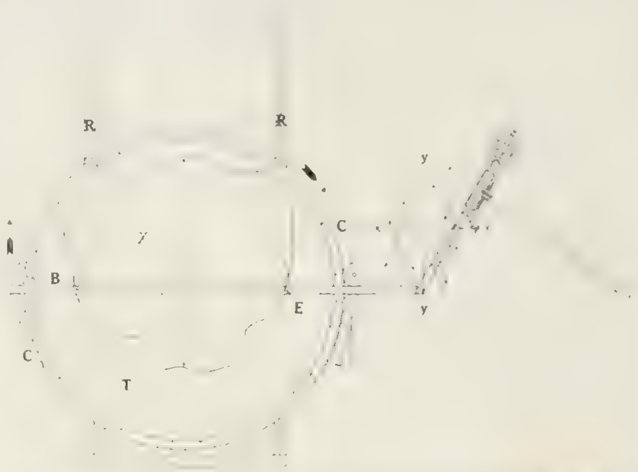

FIG. 9—ANALYZER SET TO DETERMINE THE SINE COMPONENTS

chines, etc., and resorted to the cut-and-dry method of correcting such faults which in most cases is longer or totally unsatisfactory. With a polar oscillograph and the analyzer here described, many perplexing problems which come to the electrical engineer can be worked out in a scientific way, and with a minimum of time and expense.

Arguments Against Light

THE "Jahrbuch für Gastechnik" for the year 1912 contains the following arguments against the illumination of streets by the means of gas, reprinted from the "Koelnische Zeitung" March 28, 1816.

"The illumination of streets at night by means of gas is objectionable for the following reasons.

1—From the theological standpoint. Artificial illumination is an attempt to interfere with the divine plan of the world, which has preordained darkness during night time.

2—From the juridical standpoint. Those people who do not want gaslight ought not to be compelled to pay for its use.

3—From the medical standpoint. The emanations of illuminating gas are injurious. Moreover illuminated streets would induce people to remain later out of doors and this would lead to an increase in ailments caused by colds.

4—From the moral standpoint. The fear of darkness will vanish and drunkenness and depravity increase.

5—From the view point of the police. The horses will get frightened and the thieves emboldened.

6—From the point of view of national economies. Great sums of money will be exported to foreign countries.

7—From the point of view of the common people. The constant illumination of streets by night will rob festive illuminations of their charm."

Measuring Idle Volt-Amperes

H. B. Taylor

In direct-current circuits, the watts are the same as the volt-amperes, but in alternating-current circuits, due to the phase angle between the current and the voltage, the true power is nearly always less than the volt-amperes. The true power in an alternating-current circuit can be expressed as being equal to the product of the volt-amperes, into the cosine of the phase angle or the power-factor. Another and equivalent expression for the true power or watts would be that it is equal to the voltage, times that component of the current which is in phase with the voltage. That component of the current which is at right angles to the current, thus producing no power, is called the wattless component. When multiplied by the voltage, it is called the wattless component of the volt-amperes and may be expressed as the product of the volts, amperes, and sine of the angle of lag. Thus there are the following quantities that may be measured by instruments:—

Volts	(E)	(Voltmeter)
Amperes	(I)	(Ammeter)
Cosine of Angle	(Cos Φ)	(Power-factor meter)
True Watts	(I E Cos Φ)	(Wattmeter)
Apparent Watts	(I E)	(Voltmeter and ammeter—product of two instrument readings)
Sine of Angle	(Sin Φ)	(Wattless factor meter)
Wattless Component	(I E Sin Φ)	(Wattless component meter)

Instruments for indicating phase angle or factors based upon the phase angle have their most useful application in plants containing rotaries or other synchronous machines which enable the attendant to control these factors. Some power station operators prefer instruments which indicate the wattless component of an alternating-current circuit rather than the power component. Preference for this type of meter instead of the ordinary power-factor meter is largely for psychological reasons. At fairly high power-factors the wattless component of a given load is large as compared with the difference between the percent power-factor and one hundred percent. For instance, 97 percent power-factor really means practically the same thing as 25 percent wattless factor. But the power station attendant who sees the power-factor meter indicating 97 percent may think that is good enough for all practical purposes, while if the meter indicates that a 25 percent component of the current is idle, he may bestir himself to better the conditions.

TABLE I.—COMPARISON OF WATTLESS FACTOR AND POWER-FACTOR.

Phase Angle	Percent Power-Factor	Percent Wattless Factor	Ratio of Idle to Power Component
Φ	cos Φ	sin Φ	tan Φ
0°	100	0.0	0.000
11° 28′	98	19.9	0.203
18° 12′	95	31.2	0.329
25° 51′	90	43.6	0.484
36° 52′	80	60.0	0.750
45° 35′	70	71.4	1.02
53° 8′	60	80.0	1.33
60° 0′	50	86.6	1.75
66° 26′	40	91.6	2.29

The ratio of the idle component to the power component is equal to the tangent of the phase angle. Comparisons of these values show that the wattless factor of the average alternating-current circuit is quite large. Various power-factors with corresponding phase angles and other data are given in Table I.

There are two kinds of meters for the purpose of keeping the attendant informed as to the wattless component. One of these, called a "wattless-factor meter," as distinguished from the power-factor meter, is made on the same plan as the power-factor meter but has the scale marked to read the wattless or sine component of the volt-amperes, instead of the power or cosine component. When the angle of lag or lead is zero, the cosine of the angle is unity and the sine is zero. The power-factor meter indicates 100 percent and the wattless factor meter indicates zero under this condition.

The wattless factor meter scale reads directly in percentage of idle current component, independent of the actual load on the circuit. There is no essential difference between it and the power-factor meter except the scale marking. This kind of meter favors the highest efficiency of operation at all loads, although it does not emphasize the importance of keeping down the wattless factor at any particular load. A wattless component meter indicates the total wattless component of the volt-amperes in the circuit, regardless of the power-factor, in the same way that the wattmeter indicates the total power component. It differs from a wattmeter only in the way it is connected to the circuit. This type of meter has the advantage of giving a more emphatic indication when the circuit is heavily loaded, coupled with the disadvantage that its indication is liable to escape attention at relatively small loads.

To make a wattmeter read the wattless component instead of the power component of a two-phase circuit, it is necessary only to interchange the voltage connections as shown in Fig. 1. The voltage of phase *A* is then across the potential windings for phase *B* and vice-versa, thus obtaining the proper 90 degree shift in voltage for reading the wattless volt-amperes. The potential transformers, of course, need no special taps.

Three-phase circuits can have wattless component indicators connected through transformers with special taps, which are arranged to give connections for the voltage coils of the meter, 90 electrical degrees from the voltage which is applied when the meter is connected to read watts. The angles between the current and the voltage in the meter elements at unity power-factor are then 60 degrees, lag and lead respectively, in place of 30 degrees lead and lag, as in a wattmeter under the same conditions.

Connections are given in Fig. 2 for operating a polyphase wattmeter to indicate either watts or the wattless component, by throwing a four-pole double-throw switch. Voltage transformers have leads brought out at 57.7, 100, and 115.4 percent of the normal voltage for which the potential coils of the watt-

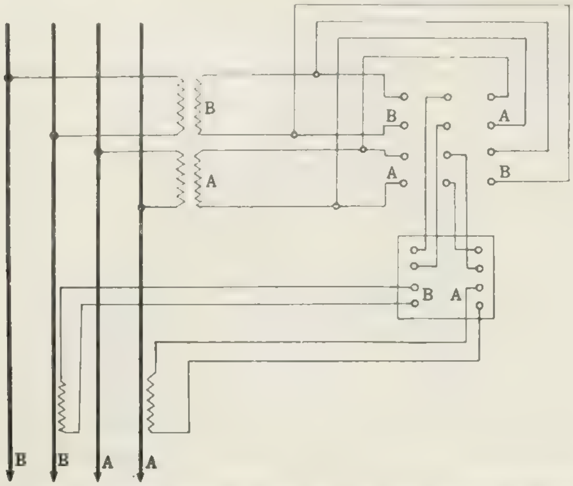

FIG. 1—WATTMETER CONNECTIONS FOR READING WATTLESS VOLT-AMPERES ON A TWO-PHASE CIRCUIT

When the four-pole, double-throw switch is thrown to the left, the meter reads watts; to the right, wattless volt-amperes.

meter are wound. (In practice it is found that 57.5 and 115 percent taps allow simpler transformer design and are sufficiently accurate.) Referring to Fig. 3, it will be noted that the voltage from the outer end of each secondary winding to the middle point of the other is $\sqrt{(115)^2 - (57.)^2} = 100$ volts and is exactly at right angles to the normal potential. A meter which reads watts with its voltage coils connected at *AC* and *BC* will read wattless component on the same cir-

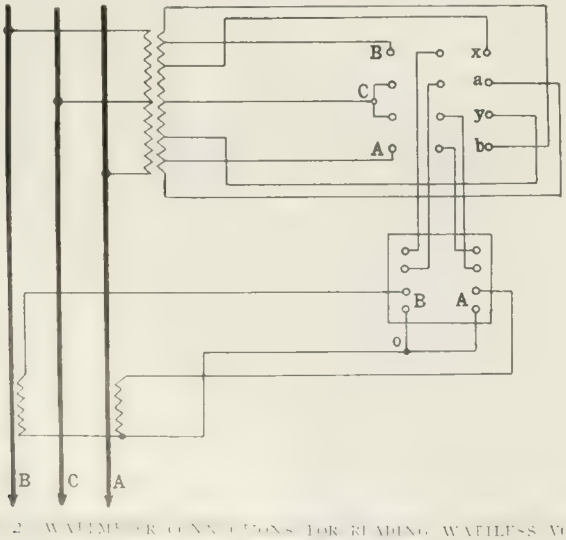

FIG. 2—WATTMETER CONNECTIONS FOR READING WATTLESS VOLT-AMPERES ON A THREE-PHASE CIRCUIT

When the four-pole, double-throw switch is thrown to the left, the meter reads watts; to the right, wattless volt-amperes.

cuit when its voltage connections are changed to *by* and *xa*. With the double-throw switch, Fig. 2, thrown to the left, the voltages *AC* and *BC* are impressed across the wattmeter and the meter indicates watts. In Fig 3, *AO* and *BO* represent the current vectors at unity power-factor, voltage *AC* and current *AO* being connected to one side of the meter and voltage *BC* and current *BO* to the other side. With the switch thrown to the right, Fig. 2, the voltages impressed on the wattmeter are *by* and *xa*. It will be noted that voltage *by* is of the same magnitude as *AC* and replaces it; consequently the voltage across this element of the wattmeter is now shifted 90 degrees with respect to the voltage previously applied. Similarly *xa*

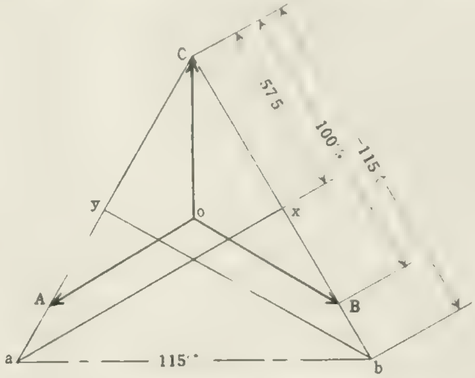

FIG. 3—VECTOR DIAGRAM

Illustrating the relation of voltages and current necessary to read wattless volt-amperes.

replaces *BC*, and the condition required to indicate wattless volt amperes is obtained.

Instead of using transformers with special taps, standard transformers and a meter with special resistors can be used to accomplish the same result. In this case the voltage between the middle and outer ends of the *V* connection will be the normal secondary voltage of the transformer, and the meter will be calibrated to read the load corresponding to that voltage when the actual voltage impressed on it is 86.6 percent of normal. The voltages indicated in Fig. 4 will then apply, all of the voltage values given in Fig. 3 being multiplied by 0.866. The coils shown will represent

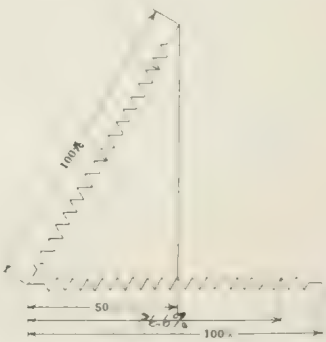

FIG. 4—VOLTAGE RELATIONS NECESSARY FOR READING WATTLESS VOLT-AMPERES ON A THREE-PHASE CIRCUIT BY MEANS OF RESISTANCES INSTEAD OF TRANSFORMERS

non-inductive resistors *V*-connected to the potential transformers. This is not as good a scheme, because the resistors cannot be designed to take enough current to make the effect of the shunt current in the meter negligible without placing an excessive load on the voltage transformers. There may be some application for it on low voltage circuits, which do not require instrument transformers, and where the energy consumed by the resistors is not objectionable.

Drilling Square and Hexagonal Holes

C. B. Auel

OUR conception of drilling has so long been associated with round holes that when told square and hexagonal holes may be drilled in metal with almost the same facility, one is apt to exclaim that the idea is preposterous. In this age of surprising accomplishments, it is, however, best to proceed slowly before saying anything is impossible, and thus it is with drilling.

Square holes are usually formed either by punching, or with the aid of a drill and a slotter. While the process herewith described is quite recent as compared with the drilling of round holes, nevertheless it is at least twenty years old and perhaps many years older, having been regularly employed by the Westinghouse Electric & Mfg. Company for that length of time in the manufacture of special wrenches, tapping-sockets, pneumatic chisel-bushings, and the like, which are required in small lots and which therefore cannot be purchased in the open market.

FIG. 1—COLLAR OR GUIDE FASTENED TO PIECE IN WHICH SQUARE HOLE IS TO BE DRILLED

When drilling in brass, no preliminary operation is required, but in the case of steel, it is necessary first, to drill a round hole, in diameter equal to that of a circle which can be inscribed in the desired square or hexagonal shaped hole. A curious feature in drilling a polygonal hole, is that the drill must have lips or sides equal in length to, but one less in number than the sides of the hole required; for example a square hole would be drilled with a triangular or three-sided drill; a hexagonal or six-sided hole with a pentagonal or five-sided drill; and so on. The operations are exceedingly simple and may be described briefly as follows:—

FIG. 2—TRIANGULAR DRILL AND SPECIAL HOLDER FOR USE IN DRILLING SQUARE HOLES

A piece of brass into which a square hole is to be drilled, is first provided with a collar or guide for the drill as shown in Fig. 1, the hole in the guide being exactly the same size and shape as that of the finished hole desired. The piece is then chucked in a lathe, and rotated, while a triangular drill, Fig. 2, its sides each equal (less clearance) to the sides of the square, is then forced home. If more convenient, the operation may be reversed, the drill being rotated and the piece held. The drill must be allowed to float by means of a taper pin or the equivalent, to keep it from binding. Holes may be successfully drilled in this manner to a depth approximately twice their diameter, without any twisting or swerving. It is customary to drive a drift through the hole finally for a fine finish. Fig. 3 shows a variety of pieces made in the manner described.

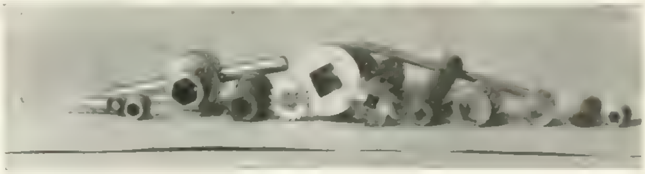

FIG. 3—A VARIETY OF PIECES IN WHICH SQUARE AND HEXAGONAL HOLES HAVE BEEN DRILLED BY THE METHOD DESCRIBED.

The principle involved will be readily understood by reference to Fig. 4, in which *a*, *b*, *c* and *d* represent the four sides of the guide with a square hole the same size as the hole to be drilled, while *e*, *f* and *g* are the sides of the triangular drill. With rotation of the drill assumed to be clockwise, the drill is pivoted for an instant in the corner *b* of the guide until the point *e* of the drill reaches the corner *a* of the guide, where it is then pivoted for a like instant until the point *g* of the drill reaches the corner *d* of the guide and so on. In following the guide in this manner, the drill naturally makes the same kind of a hole in the metal back of the guide and over which the latter fits and thus the drilling of a square hole is accomplished. When drilling a hexagonal or six-sided hole, a pentagonal or five-sided drill must be used, as already stated, each side of the drill being equal (less clearance) to a side of the hexagonal guide. The actual drilling is, of course, done by the ends of the drill, the sides of which take no part in the forming of the hole, merely serving as supports against the sides of the square guide.

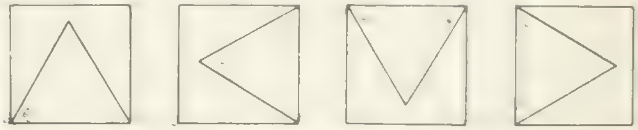

FIG. 4—SKETCH SHOWING HOW HOLES ARE DRILLED

Shop Testing of Electrical Apparatus—XIV

INDUCTION MOTORS

FOR TEST PURPOSES, induction motors may be divided into polyphase and single-phase types. There are a number of methods of testing and calculating test results for each, the differences between the methods for the two types being due to the presence of the starting windings or devices in the single-phase machine, and the peculiar flux relations in its operation.

The three common methods of determining the characteristics of either polyphase or single-phase induction motors are the graphic or circle-diagram method, the brake test, and mathematical calculation.

To establish the complete performance of a polyphase motor, the following characteristics must be determined:—Efficiency, power-factor and speed over the entire range of load at normal voltage and frequency, the ratios of its starting and of its maximum or pull-out torque to its full-load torque, and also the ratio of the line current when starting under full-load torque to the line current when operating at normal load. A mechanical examination for undue vibration and noise is made during the temperature run.

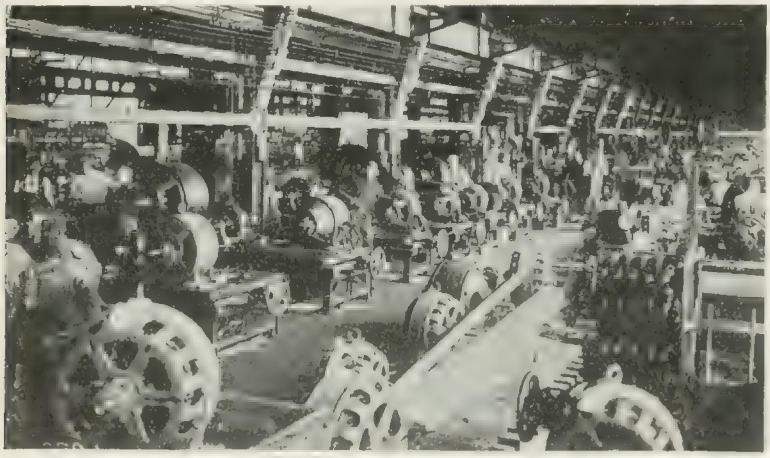

FIG. 1—GENERAL VIEW OF A TYPICAL INDUSTRIAL MOTOR TEST FLOOR

THE CIRCLE DIAGRAM METHOD

The diagram which will be used in this discussion is the Specht diagram which is a refinement of the Heyland or McAllister diagrams. Three readings only are necessary for its construction; namely, the resistance of the primary winding at normal operating temperature, readings of current and power at normal voltage with the motor running idle and readings of current and power at normal voltage with the rotor of the motor locked.

Resistance Readings are taken on the machine when cold and also after each of the temperature runs. On the primary, the resistance is taken between terminals and, in the case of wound rotors, between rings on the secondary, the potential points being held directly on the rings and not on the leads or brushes.

The room temperature must be noted carefully in each case. If there is any reason to suspect, when taking the cold resistance, that the windings of the machine are at a different temperature from the room, thermometers should be placed directly on the windings and their readings noted along with the temperature of the room.

Readings of Current and Power—Motor Running Idle—While readings at normal voltage only are sufficient for the determination of the performance of the motor it is desirable to take a number of readings at different voltages and plot curves to ensure accuracy. These curves are usually termed the running saturation curves of the motor and are useful in determining many features of the design, as well as the true value for the current and power at normal voltage. It is good practice whenever possible to make temperature runs before taking the running saturation curves so that the bearings may be worn in to approximately normal condition before the test. In taking the running saturation of a machine, it is connected to the line with wattmeters, ammeters and voltmeters in the circuit. A polyphase wattmeter or two single-phase meters are necessary for greatest accuracy. Where only one single-phase meter is available, in the case of very small power or fan motors, some arrangement must be made so that, while taking the readings in one phase or lead, an impedance equivalent to that of the meters used can be placed in series with each of the other leads so as to avoid any excessive unbalancing of the circuit.

Before starting the motor to be tested, the wiring and transformer connections should be checked carefully. The machine is brought up to speed and checked mechanically for end-play, lubrication, etc. After the friction in the machine has become constant, as indicated by constant wattmeter readings, the voltage is brought up to about 33 percent above normal and a reading of current and watts taken, the current being read in all phases. The algebraic sign of the wattmeter readings should be carefully noted. A reversal of the connections to get a positive deflection indicates that the difference between the two readings must be taken to get the true value of the power. The voltage is lowered in about 10 percent steps, one step being at normal voltage, taking each reading at each step, until the speed of the motor breaks, i. e., drops

off rapidly. This point is generally indicated by the current going up as the voltage is lowered. Care should be taken, in changing from one step to another, that the machine has assumed the condition due to the voltage held before a reading is taken. The stability of the wattmeter reading is a fair indication of the proper time to take a reading. During this and the succeeding tests, care should be taken that the frequency remains at the motor's rated value, and that the voltage on the different phases remains balanced.

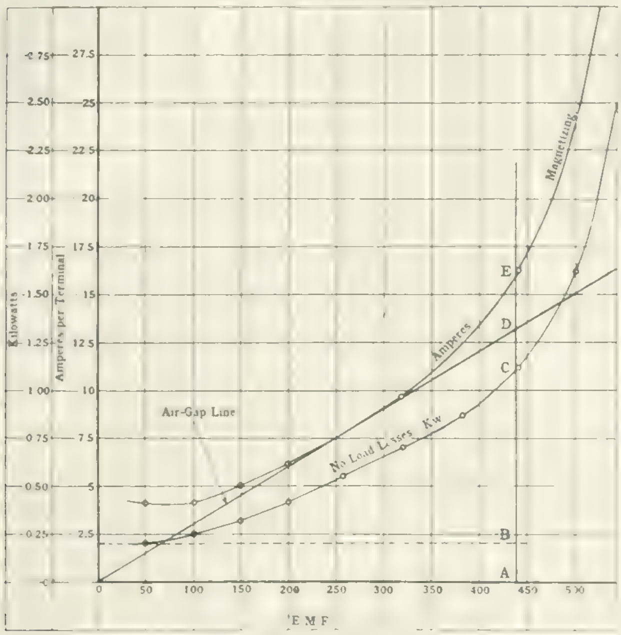

FIG. 2—RUNNING SATURATION CURVES

The air-gap line is drawn tangent to the curve of magnetizing amperes, since at low voltage and nearly synchronous speed, the excitation required for the iron is considered negligible. The error involved is slight, although the ampere-turns required for the iron are never quite zero, and there is always a slight saturation factor.

A typical set of results for such a test on a 50 horse-power three-phase, 440 volt 25 cycle, 6 pole induction motor is given in Table I. and the corresponding curves in Fig. 2. In making such a test, the readings actually taken should be recorded, together with meter calibrations and voltage ratios, if transformers are used. The readings given in Table I, are derived from an actual test, the amperes being the average amperes per phase and the watts the result of readings by the two wattmeter method. The information to be derived from these results is indicated in Fig. 2, as follows:—

TABLE I—RUNNING SATURATION

Volts	Amperes	Watts
556	36.23	2640
500	25.08	1640
444	16.30	1160
380	12.08	880
320	9.75	700
260	7.58	540
200	5.91	440
150	5.05	295
100	3.50	280
50	3.75	227.5

Motor starts at 58 volts—runs quietly—no dead points.

The friction and windage losses are indicated by the ordinate *AB*, the watts read at the last point in the test, the core loss being practically negligible at this low voltage, and the speed being nearly synchronous. Then referring to the curve of watts at the normal voltage point, the core loss is determined by the difference between *AC* and *AB*, which equals *BC*. This value also includes the no-load copper losses which should be subtracted, particularly on small machines, where it may be a considerable part of the watt reading at no load. The magnetizing current required for the air-gap alone varies in a straight line as shown, and the ratio of the total magnetizing current *AE* to this value *AD* at normal voltage determines (and is defined as) the "saturation factor" of the machine.

Readings of Current and Power at Normal Voltage—Rotor Locked—In taking the locked saturation readings, the motor is connected as for the running saturation. Meters should be selected with care; in no case should part of a curve be taken with a series transformer and part with the meter alone; wattmeters will stand 100 percent overload in current long enough to get a reading. Readings should be taken at as near the same temperature as possible, the higher values being taken first so that the motor will be hot for all. If it becomes too hot at any time it should be allowed to run light for a few minutes to cool off before taking the next reading. In the case of wound-rotor machines the secondary should be short-circuited, this short-circuit being inside the brushes, that is, at the rings, if at all possible. With about full-load current on the stator, the rotor should be moved over a space equivalent to a pole pitch and the position of maximum current noted, and the rotor is then locked in this position for the locked tests. In determining this maximum current all phases should be read, as the maximum shifts from one phase to another as the rotor is moved. The maximum current position also corresponds to that of maximum torque, and it may be more convenient in the case of some of the smaller machines to make the torque the distinguishing feature. It is generally not advisable on account of undue heating to take the readings with the rotor locked at normal voltage except in the case of some small machines with wound rotors. The normal voltage values are calculated from readings taken at lower voltages on the assumption that the current varies directly as the voltage, and the watts as the square of the voltage. This assumption does not hold good in many cases of small motors, high-torque machines or in other special cases. Sufficient points must then be taken to determine a curve and the normal voltage values obtained from the curves or their logical extensions. Readings may be taken as high as three or four times normal current without injury to the machine, provided this current flows for a short time only.

The readings in the first three columns of Table II represent actual test values, while those in the last two columns were calculated according to the above assumptions, for normal voltage. The curves of amperes and kilowatts in Fig. 3 are plotted from the test values and then extended, as shown by the dotted lines, to normal voltage, as a check on the calculated values. It is evident from the calculations in Table

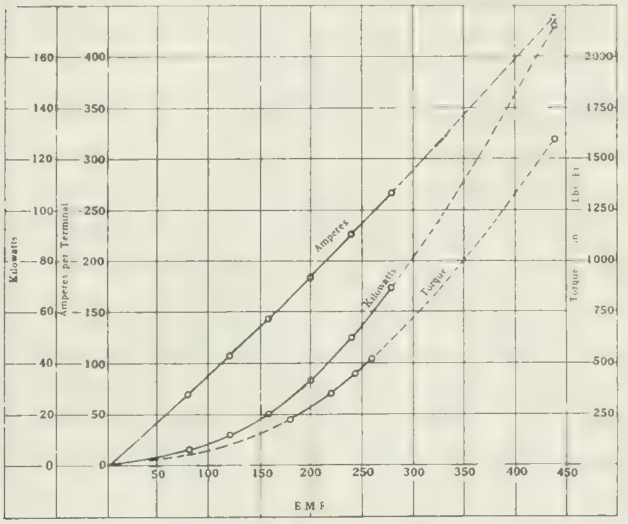

FIG. 3—LOCKED SATURATION CURVES

The dotted portion represents a logical extension to full voltage of the curve determined by actual readings at the lower voltages.

II that the assumptions made are not strictly correct, since the calculated values increase as the voltage increases, instead of being all the same. So some higher value than any there resulting should be used in the construction of the diagram. The ampere curve very readily determines this value for the amperes. It will be seen that the power-factor stays about constant throughout the test; therefore, assuming an average power-factor, the kilowatts may be calculated as well.

On motors with wound secondaries, in addition to the running and locked saturation curves, an open saturation curve is taken. As the name implies

TABLE II—LOCKED SATURATION.

Test Values			Power Factor	Calculated to 440 volts	
Volts	Amps. per Terminal	Kw		Amps. per Terminal	Kw
280	269	68.4	52.4	422	169
240	224	48.6	52.4	411	164
200	184	32.8	51.6	405	159
160	140	19.5	50.3	385	148
121	105	11.3	51.3	382	150
80.5	68	4.95	52.2	372	148

the leads of the secondary are left open; voltage is impressed on the primary in the same manner as for the running saturation and the same readings taken as in that test, the voltage between terminals on the secondary being also read. The data is recorded and plotted in the same general manner as that of the running saturation and should check very closely to the values there obtained.

The ratio of the primary to the secondary electromotive force is frequently used to calculate the kilowatts taken when the rotor is locked, the calculated value giving better results than the tested value in cases where, because the secondary frequency is much higher than normal, the eddy currents are excessive when taking the locked saturation in the ordinary way. It is evident that the power consumed in taking the locked saturation is dissipated only in the copper losses in primary and secondary and in eddy current losses. The eddy current loss is rather indefinite but may be assumed to be between 20 and 30 percent of the secondary loss, depending on the type of winding on the rotor.

Let I_0 = Primary current—no load— Equivalent single-phase amperes).

I_L = Primary current—locked—(Equivalent single-phase amperes).

E = Primary electromotive force (normal voltage).

E_s = Secondary electromotive force at E primary electromotive force.

I_s = Secondary current locked $= \frac{E}{E_s} \times I_L$.

R = Primary resistance between terminals.

R_s = Secondary resistance between terminals.

X_1 = Primary reactance.

X_2 = Secondary reactance in terms of the primary, or the "equivalent" secondary reactance.

Then the primary copper loss $= (I_L - I_0)^2 \times \frac{R}{2}$

The secondary copper loss $= I_s^2 \frac{R_s}{2}$

The eddy current loss $= K\left(I_s^2 \frac{R_s}{2}\right)$

K, as previously noted, varies from 0.2 to 0.3, depending on the type of winding whether wire, strap, or bar. The total locked kilowatts then will be the sum of the above three losses. The amperes are determined in the ordinary way as already explained.

CONSTRUCTING THE CIRCLE DIAGRAM

All the necessary values are now available for the construction of the circle diagram of this motor, the cold resistance at 25 degrees Centigrade being 0.197 ohms between terminals.

The resistance at 60 degrees C. is used for the diagram as being about the limit to which the windings of a motor under normal operation will rise, being equal to the resistance at 25 degrees C. multiplied by 1.135. Below is a summary of the values from the test. These are taken from the smooth curves plotted from the actual readings. The amperes per terminal in each case must be reduced to equivalent single-phase amperes by multiplying by the square root of three for three-phase and by two for two-phase before being used in formulæ for the diagram itself.

No Load	Symbol		Symbol	Locked
440	E	Volts	E	440
16		Amperes per terminal		436
		Equivalent Single-Phase		
27.7	I_0	Amps.	I_L	756
1.14	W_0	Kw	W_L	173
9.35	Cos Φ_0	P. F.	Cos Φ_1	52

Additional data necessary for the construction of

the diagram is determined from the following formulæ:

$$R_1 = \frac{\text{Res. between Terminals at } 25^\circ \text{C.} \times 1.135}{2}$$

$$= \frac{0.197 \text{ ohms} \times 1.135}{2} = 0.1118 \text{ ohms}$$

$$\text{Tan. } e = \frac{2\,(I_0 \times R_1)}{E} = \frac{27.7 \times 0.1118 \times 2}{440} = 0.0141$$

$$X_1 + X_2 = \frac{E\sqrt{1 - \text{Cos}^2\,\phi_L}}{I_L} = \frac{440\sqrt{1 - 0.52^2}}{756} = 0.497$$

$$\text{Cotan}\,\phi = \frac{R_1}{X_1 + X_2} = \frac{0.1118}{0.497} = 0.225 \text{ or } 22.5 \text{ percent}$$

For motors under five horsepower or other motors where the copper loss at no load is a large part of the total loss at that load some slight modification of the above formulæ are necessary, as will be explained later.

Referring to Fig. 4, the construction is as follows:

Assume a base line AB. With A as a center and a radius 100 units long draw a quadrant of a circle as indicated. This is the power-factor circle, power-factor being read directly on the scale to the left of the sheet. On this circle lay off the no-load and locked power-factors, 9.35 percent and 52 percent respectively, determining P_L. On the lines joining these points to the center of the power-factor circle A lay off from A to any convenient scale the no-load and locked amperes 27.7 and 756 on their respective lines determining points C_0 and C_L respectively. The scale used should be so selected as to give as large a diagram as possible, this being determined by the location of the locked-ampere point. In this case the forty scale of the engineers' rule is used, twenty amperes being equal to one division on that scale. This scale is used in measuring all current values on the diagram. Now join C_0 and C_L extending the line to cut the base line, determining point E, which will be used a little later in connection with efficiency.

On a line drawn through C_0 parallel to the base line, lay off 100 units from C_0 to as large a scale as possible. (Fifty units on the 60 scale of the engineers' rule will usually be found most convenient.) To this same scale at the 100-point lay off the value of tan e at right angles, and join the points thus determined to C_0. The intersection of this line with a line drawn perpendicular to line C_0 C_L at its middle point determines the center of the current circle. Draw in this circle, being careful that it passes accurately through points C_0 and C_L. At point C_0 erect a perpendicular to the tangent line C_0 T, extending it indefinitely to some point, as D; parallel to this line C_0 D draw another line through point E extending it indefinitely to some point, as K. These are reference lines for the slip and efficiency respectively. At the point where the power-factor circle cuts the base line, to the same scale as the power-factor and perpendicular to the base line lay-off contan ϕ. Determine where a line drawn from A through this point will cut the current circle and from the point of intersection draw a line back to C_0. The percent slip is measured on a line 100 units long to any convenient scale drawn parallel to this cotangent line between lines C_0 D and C_0 C_L; on another line 100 units long, preferably to the same scale as the slip line, drawn between E K and C_0 C_L parallel to the base line, the percent efficiency is measured. These lines must be located by trial, sliding the scale along parallel to the proper line until the correct distance is located. The twenty scale

For a scale of percent efficiency and percent slip. [illegible]

of the engineers' rule is the best to use in ordinary cases.

The diagram is now ready to be used for determining the performance at any load desired. It is the practice to determine at first only the normal load values, except where guarantees are made at fractional loads, when these also are to be calculated.

To determine the values for full load, calculate the amperes corresponding to the rated horse-power on the basis of 100 percent power-factor and 100 percent efficiency. Lay off these amperes on the line $E\ K$, using the same scale as previously used for the no-load and locked currents. A line through this point drawn parallel to the locked current line $C_o\ C_L$ cutting the current circle determines the normal current point, and the actual value is determined by measuring the distance from the point back to point A to the same current scale as before. The point of intersection with the power-factor circle of a line drawn from A through the normal load current point determines the power-factor and it is read directly from the scale to the left. The efficiency is determined by the intersection of a line drawn from E through the current point with the efficiency line. The value of efficiency is the percentage of the efficiency line between this intersection and the $C_o\ C_L$ line. In like manner a line from C_o through the same point cutting the slip line determines the slip. The actual value of the slip is that percent of the slip line between the line $C_o\ D$ and the above point of intersection.

Having determined the efficiency, power-factor and slip for a given load or brake horse-power, the real horse-power, apparent horse-power and corresponding current may be readily calculated; also the torque in foot-pounds for that particular load by the following formulæ:

$$\text{Real h p} = \frac{\text{Brake h p}}{\%\ \text{Efficiency}} \qquad \text{Current} = \frac{\text{Apparent h p} \times 746}{\text{e. m. f.}}$$

$$\text{Apparent h p} = \frac{\text{Real h p}}{\%\ \text{Power Factor}} \qquad \text{Torque} = \frac{\text{Brake h p} \times 5250}{\text{Speed}}$$

$$\text{Speed} = \text{Synch. Speed} - (\text{Synch. Speed} \times \%\ \text{Slip}) \text{ or } \frac{\text{Frequency} \times (100 - \%\ \text{Slip})}{\text{No. of Poles}}$$

The ratio of the full-load torque to the starting torque and maximum torque are also determined from the diagram. Draw lines perpendicular to cotangent line $C_o\ N$ at the normal load current point and at point C_L also one passing through the center of the current circle extending it to cut that circle. The portion of these lines between the cotangent line and the current circle are proportional to the full-load, the starting, and the maximum torque respectively. The actual ratio is determined by dividing the length of the starting torque and the maximum torque lines by the full-load torque line. These are measured to any convenient scale but preferably to that of the efficiency and slip. The values in foot-pounds may readily be obtained by multiplying the full-load torque already determined by the ratio for that value desired. The starting current necessary to give full-load torque in any case varies inversely as the starting torque, and is equal to the locked current divided by the ratio of the starting torque to the full-load torque.

After once obtaining the various values for full load it will be evident how the values for any other load may be determined. The complete results may be tabulated as in Table III and curves as per Fig. 5 plotted from the data. If the measurements from the

TABLE III—PERFORMANCE DATA FROM DIAGRAM

Percent Load	0	25	50	75	100	125	150
Amperes—total	27.7	37.0	54.8	76.8	101.0	126.8	155.0
Percent power-factor	9.35	66.2	85.0	90.4	93.2	94.0	94.5
Percent efficiency	0	86.8	90.6	91.0	90.2	88.9	87.6
Percent slip	0	1.2	2.4	3.5	4.6	5.8	7.1

VALUES CALCULATED FROM ABOVE DATA

Amperes per terminal	16	21.3	31.6	44.3	58.2	73.0	89.5
Brake horse-power	0	12.5	24.9	37.2	50.0	62.5	75.7
R. P. M.	500	494	488	482	477	471	464
Torque—lbs-ft.	0	134	258	405	550	698	856

diagram are carefully taken and the calculations accurately performed all the points must lie on the smooth curves; these curves checking with each other at all points.

In addition to the data in Table III, the following ratios complete the performance information for the motor:

$$\text{Ratio, } \frac{\text{Starting torque}}{\text{Full-load torque}} = 2.78$$

$$\text{Ratio, } \frac{\text{maximum torque}}{\text{full-load torque}} = 3.89$$

$$\text{Ratio, } \frac{\text{starting amperes}}{\text{full-load amperes}} = \frac{\text{locked amperes}}{\text{starting torque ratio} \times \text{full-load amp.}} = \frac{756}{2.78 \times 101} = 2.69$$

The amperes as determined above are for the condition that the motor is starting at full load torque.

It is always best to check the efficiency as obtained from the circle diagram by the separate loss method. The efficiency by separate losses should check within half of one percent of the diagram value. If the discrepancy is materially more than that, some error in calculation or construction has been made and should be corrected before tabulating results.

Below are the necessary formulae for calculating this efficiency; full-load current and the percent slip are taken as derived from the diagram. However, if the actual efficiency by losses on the motor itself is desired instead of only a check on the diagram results, the actual slip should be determined by test and used in the formulae instead of the diagram value.

The following calculations are for full load.

Constant Losses

Friction, windage, and iron losses $W_o - I_o^2\ R^1 =$
$1140 - (27.7^2 \times 0.1118) =$ ....1054 watts

Variable Losses

Primary copper loss = (F. L. Amps.)^2 (diagram)
$\times R_1 \quad 101^2 \times 0.1118$ 1140

$$\text{Secondary copper loss} = \frac{\text{Rated hp} \times 746}{100 - \%\ \text{Slip}} \times \%\ \text{Slip} =$$

$$\frac{50 \times 746}{100 - 4.6} \times 4.6 = \text{ .... } 1800$$

Output in kw = Rated hp × 746 = 50 × 746 = 37300

Input in kw = Sum of above four values = ... 41294

$$\text{Efficiency} = \frac{\text{kw output}}{\text{kw input}} \text{ .... } \frac{37300}{41294} = 90.2\%$$

In the above formulæ the amperes used are the equivalent single-phase or total amperes. If it is desired to calculate the efficiency, using amperes per terminal, the first two formulæ become:

Friction and windage .... $W_o - 1.5\, I_o^2 R$
Primary copper loss .... $1.5\, I_{FL}^2 R$

Where I_o = Amperes per terminal—no load.
I_{FL} = Amperes per terminal—normal load
R = Resistance between terminals at 60 degrees C

As previously noted for motors under five horsepower and in some cases of larger sizes, where the copper loss at no load is a considerable portion of the total no-load losses, some modification must be made in the construction of the diagram.

In addition to the ordinary no-load power-factor, ($\cos\phi_o$) as found by the formula

$\dfrac{\text{N. L. Watts}}{\text{N. L. amperes} \times \text{volts}}$, the power-factor ($\cos\phi'_o$) that would result if there were no copper loss is also ascertained, the formulæ becoming

$$\frac{\text{N. L. watts} - (\text{N. L. amps.}^2 \times R_1)}{\text{N. L. amperes} \times \text{volts}}$$

The formula for the tangent line is also changed to account for the excessive induction in such cases, becoming

$$\frac{\text{No-load amperes} \times [(X_1 + X_2)\ \text{Cos}\,\phi'_o + R_1]}{\text{Normal e. m. f.}}$$

In the construction of the diagram both $\cos\phi_o$ and $\cos\phi'_o$ are laid off on the power-factor circle and connected to the point A, the same no-load amperes being laid off on each.

The line $C_o\,C_L$ is drawn through the no-load point on the $\cos\phi_o$ line as usual. However, all other lines through the no-load point, that is the tangent, the cotangent and the slip are drawn from the no-load point located on the $\cos\phi'_o$ line.

In any case where the values for $\cos\phi_o$ and $\cos\phi'_o$ do not differ more than two percent, it is not necessary to make any modification and the diagram should be constructed according to the standard method.

THE PRONY BRAKE METHOD

The prony brake method of determining the performance of a motor is well known. This method is inherently subject to great inaccuracies and only by the very careful use of first-class apparatus can consistent results be obtained. For commercial work the difficulty of obtaining close regulation and of properly dissipating the heat generated prohibit its use except in the smaller size motors, from approximately 75 horsepower down. Even in these cases it is only used ordinarily as a check on loss methods, a normal load reading only being taken. However, in cases of small high-torque machines, small single-phase or very small polyphase motors, the brake test seems to give even more reliable results than the loss methods.*

*For a description of the use of the prony brake, see the Journal, Vol. I, p. 420, Vol. III, p. 523, Vol. IV, p. 118, Vol. IX, p. 577.

In the use of the brake care must be taken that the pulley is well balanced, that the brake arm rides freely and without excessive vibration, that the water disposing devices are so placed as not to consume any energy. The length of the arm and the tare of the brake enter directly into the results and should be determined accurately before each test, the tare being determined by balancing the brake on a knife edge, the fulcrum being a line parallel with the shaft, vertically above the center of the pulley when the brake beam is held horizontal. Care should be taken that all accessories used on the brake during the test are in place when taking the tare; also that any blocks placed on the scales are properly allowed for. The length of the arm should be measured along the center

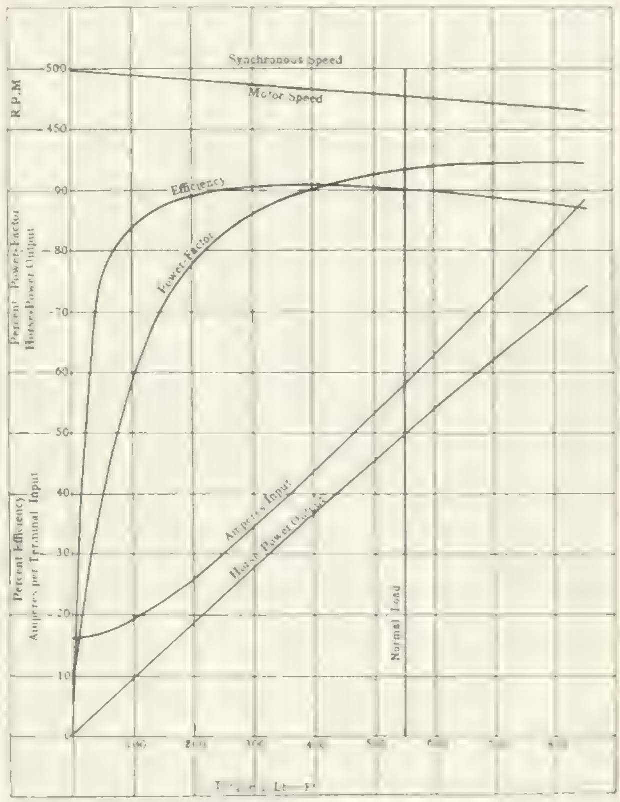

FIG. 5—PERFORMANCE CURVES PLOTTED FROM DATA OBTAINED FROM THE CIRCLE DIAGRAM

of the arm from the center of the supporting pin at the end of the arm to the vertical line above mentioned through the center of the brake pulley.

In making the actual test, the motor is connected as in the running saturation test, all transformers and plant connections checked carefully, and the proper meters installed. A low voltage is first impressed on the motor sufficient to determine whether the brake has been placed on the motor to correspond with its direction of rotation. If correct, the voltage is brought up to normal and the operation of the brake carefully observed. Note that while holding any given load there should be no adjustments made of the cooling water; great care being also taken that the operator bears no weight on the handwheel.

If only a check on the performance as determined

by the diagram method is desired, a full-load reading only is taken. The weight to be put on the brake beam for this reading is usually calculated on the basis of five percent slip but should be modified if more definite information is at hand:

Let A = tare in pounds L = length of arm in feet
$R.p.m.$ = rev. per minute. W = reading of scale in pounds.

$$\text{Then hp} = \frac{(W - A) \times L \times \text{r.p.m.} \times 2\pi}{33000} = \frac{(W - A)\, L \times \text{r.p.m.}}{5250}$$

The estimated speed on the basis of five percent slip will be synchronous speed minus 0.05 × synchronous speed. Then the weight to put on the scales will be

$$W = \frac{\text{Hp} \times 5250}{\text{Estimated r.p.m.} \times L} + A$$

With the brake adjusted to balance this estimated weight simultaneous readings of the motor speed and frequency of the supply circuit are taken and the true slip calculated.

$$\text{Percent slip} = \frac{\text{Synchronous—actual speed}}{\text{Synchronous speed}}$$

The above speeds must be taken very accurately as on them depend the calculation of the losses in the rotor, a comparatively small error having a considerable effect on the final result. If a good watch is used fairly accurate readings may be obtained with the speed counter but stroboscopic* methods of measuring the slip in r.p.m. direct are always to be preferred.

With this true slip the weight is again calculated and the proper changes made. Simultaneous readings

TABLE IV—BRAKE TEST—FULL-LOAD.

Volts	Amperes	Watts	R. P. M.	Pounds
440	59-58-57	41660	474	222
440	58-58-60.8	41700	475	222

L=2.5 feet, Tare=1 pound.

are now taken of current and watts in addition to the speed of the motor and the frequency of the circuit, the voltage being held constant at its normal value throughout the reading. This reading should be recorded as indicated in Table IV:

$$\text{Then } \frac{\text{Volts} \times \text{Amps.}}{746} = \text{apparent hp}$$

$$\frac{\text{Watts}}{746} = \text{Real hp} \quad \text{(The true hp input into machine)}$$

$$\frac{(W - A)\, L \times \text{r.p.m.}}{5250} = \text{brake hp} \quad \text{(True output from machine)}$$

$$\text{Efficiency} = \frac{\text{hp output}}{\text{hp input}} = \frac{\text{Brake hp}}{\text{Real hp}} = \frac{(W - A)\, L \times \text{r.p.m.}}{\text{Watts} \times 7.05}$$

$$\text{Power factor} = \frac{\text{Real hp}}{\text{Apparent hp}} = \frac{\text{Watts}}{\text{Volts} \times \text{Amps.}}$$

Wherever possible readings of maximum and starting torque are also taken by brake. The maximum torque or pull-out as it is commonly termed should be taken at normal voltage if possible. The load on the motor is brought up gradually by means of the brake until the pull-out point is reached, the scales being kept as nearly as possible in balance in the meantime by rapidly adjusting the weights on the scale beam.. The weight on the beam at the instant of pull-out as indicated by the sudden change in note of the motor, i. e., the maximum weight under which the motor will maintain its speed, is the pull-out. If it is not possible to take the pull-out at normal voltage it may be taken at a lower voltage, and the full voltage value calculated on the basis that the torque in pounds feet increases as the square of the voltage. At least two readings at different voltages should be taken.

The starting or locked torque should be taken over a considerable range of voltage, taking readings at as high a voltage as the heating of the motor will permit. In taking the reading, the rotor is locked by means of the brake, the arm of which rests on the scales in the usual way. The voltage should be brought up to the desired value as rapidly as possible; the weight on the scales being adjusted at the same time

TABLE V—STARTING AND PULL-OUT TORQUES.

Volts	Lbs—Ft. Torque	Lbs —Ft. Calculated to 440 V.
	STARTING TORQUE	
260	512	1500
244	440	1435
220	342	1368
180	220	1315
	PULL-OUT TORQUE	
260	671	1925
220	480	1920

L=2.51 feet, Tare=1 pound.

so that a balance may be reached without a delay as soon as the voltage is set. The power should then be cut off at once so as not to heat the motor more than is necessary. The normal voltage value of the starting torque is calculated in the same manner as stated above for the pull-out or maximum torque. A record of the results of such a test on the same motor for which the circle diagram was constructed is given in Table V.

When the starting torque values as calculated for normal voltage from the different readings vary, a curve should be plotted and the normal voltage value determined by a logical extension of the curve. The dotted portions of the curve in Fig. 3 indicate the result in this case.

This completes the brake test and the results are summarized as follows:

Amperes......102.1	Full-load torque in lbs. ft......... 552
Real hp 55.9	Starting torque in lbs. ft.........1600
R.p.m 475	Maximum torque in lbs. ft 1925

*See article by C. W. Kincaid, in the Journal for July, '13, p. 600.

From these values the following data can be calculated:

Brake hp.........50		Percent efficiency.......... 89.5	
Percent slip..... 5		Percent power-factor........93	
Ratio $\frac{\text{full-load torque}}{\text{starting torque}}$	2.9	$\frac{\text{maximum torque}}{\text{full-load torque}}$	3.5

Ratio $\frac{\text{starting amps.}}{\text{full-load amps}}$ $\frac{756}{2.9 \times 102.1} = 2.56$

For convenience the results of the test by brake and by circle diagram are tabulated in Table VI for comparison.

The values by test and diagram should check reasonably closely. If they differ more than two percent in efficiency or power-factor or more than one percent in slip, the test data for either the diagram or brake test should be checked. It is sometimes very difficult to determine just which one is in error but a careful inspection and a lining up of results will usually indicate which data to check first. It is usually considthat the results which give most nearly the real performance of the motor are: efficiency by losses; power-factor by the diagram; torques by brake test.

If a complete brake test is required, readings are taken in the same manner as described for full load, from no load to 50 percent overload, about six points being taken, the brake horse-power, the amperes per terminal input, and speed being plotted as ordinates against torque in pounds feet as abscissæ. The efficiency and power-factor curves are then calculated from the smooth curves as obtained above and not from each individual reading. The percent slip is also determined in the same manner.

TABLE VI—COMPARISON OF RESULTS BY CIRCLE DIAGRAM AND BY BRAKE TEST

Full Load of Values	Circle Diagram	Brake Test
Volts	440	440
Amperes	101	102.1
Percent power-factor	[illegible]	[illegible]
Real horse-power	[illegible]	[illegible]
Percent efficiency	[illegible]	[illegible]
Brake horse-power	[illegible]	50
Percent slip	[illegible]	5
R. p. m.	477	476
Full-load torque	550	552
Starting torque ÷ F. L. T.	2.78	2.9
Maximum torque ÷ F. L. T.	3.89	3.5
Starting amperes ÷ full-load amps.	2.69	2.56

(To be continued.)

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1026—Cost of Transmission Construction—Could you give the cost per foot of running a circuit for house lighting, in ducts underground and on poles? The transmission is alternating current at 2 200 volts, 60 cycles. I want to find out the difference in running the line in the street by these two methods, including the total cost of material, labor, etc., in each case. P. C. (RHODE ISLAND)

The cost of constructing an underground duct line varies according to the nature of the soil, the kind of paving, the depth at which ducts must be laid to conform to municipal requirements and the obstructions which are encountered in the streets. The size of a duct line necessary for residential districts would be about four ducts. However, should there be a possibility of later on using the street as a transmission artery, an eight duct subway would be more apt to suit the conditions. The difference in the cost between the two subways lies in the extra cost of ducts and concrete and the labor of laying the ducts, excavation remaining the same. Manholes should be located about 300 feet apart with junction boxes at intervals of 100 feet; the junction boxes being used for the purposes of distribution. Manholes for ordinary distribution work can be constructed for about $150—junction boxes will cost $75. The following are itemized statements of the costs of four and eight duct subways, laid six feet below the surface:

FOUR DUCT SUBWAY.

Excavating	$1.00 per [illegible]
Cost of ducts	[illegible]
Labor of laying ducts	[illegible]
Repaving charge	[illegible]
One manhole and two junction boxes to every 300 ft. of subway $300.00 or	[illegible]
Total cost of subway per lineal foot	[illegible]

EIGHT DUCT SUBWAY

Excavation	[illegible] per foot
Cost of ducts	[illegible]
Labor of laying ducts	[illegible]
Repaving charge	[illegible]
One manhole and two junction boxes to every 300 ft. of [illegible] line, $300.00 or	1.00 " "
Total cost of subway per lineal ft	[illegible]

To this there should be added the cost of underground cable and installation of same. A No. 6 duplex, varnished cambric 2 200 volt cable will average about 32 cents per foot installed and jointed.

COST OF OVERHEAD CONSTRUCTION

35 foot pole	$ [illegible]
Cross arm	1.00
Insulators and pins	[illegible]
Labor and hauling	[illegible]
Total for pole set	[illegible]

No. 6 weather proof wire will cost $14.40 per 1 000 ft. (copper at 18 cents per lb.), and will cost $8.00 per 1 000 feet to string. The cost of 1 000 feet of overhead line with poles set every 100 feet would be $104.80 or 10.48 cents per foot.

SUMMARY

Four Duct Subway and Cable...	$3.35 per ft. lineal [illegible]
Overhead construction	[illegible]

W. A. E.

1027—Power to Accelerate Motor—I have a three hp, 100 volt, 1 200 r.p.m., direct-current motor, belted to two emery wheels, 12 inches in diameter, two and one-half inches face. Weight of wheels and one and one-half inch shaft 70 lbs. How many hp would it take to bring this mass up to a speed of 1 200 r.p.m., in three seconds? Please give the formula and explain in the full method of figuring such applications. The diameter of the motor pulley and wheel pulley are both 5 inches. E. W. R. (ILL.)

The calculations are as follows, assuming the values marked*:—

	Weight Lbs.	Radius of Gyration Ft.	Moment of Inertia
Armature	[illegible]	[illegible]	[illegible]
2—5 in. pulleys	10.*	0.15*	0.22
Belt	[illegible]	[illegible]	[illegible]
2—Emery wheels and shaft	[illegible]	[illegible]	[illegible]

Total moment of Inertia about armature axis ..... [illegible]

1—Acceleration Torque—Time [illegible]

celerate to a given speed (r.p.m.) is given by following formula

$$\text{Seconds} = \frac{\text{r.p.m.}}{307} \times \frac{\text{Moment of Inertia.}}{\text{Accelerating Torque}}$$

$$\text{in which } 307 = \frac{32.16 \times 60}{2\pi}$$

$$\text{Then } 3 = \frac{1200}{307} \times \frac{11.48}{\text{Accelerating Torque}}$$

$$\text{Accelerating Torque} = \frac{1200 \times 11.48}{307 \times 3} = 15 \text{ lbs.}$$

2—Friction Torque of Emery Wheels and Total Torque

Two bearings (1.5 in. shaft diameter, Friction Torque = 1.00* lbs.

Total Torque (during accelerating period) = 15 + 1 = 16 lbs.

3—Motor Output (end of accelerating period)—

$$\text{Hp} = \frac{16 \times 1200}{5250} = 3.65$$

4—Total Watts Input—

Rheostat and motor during accelerating period (with motor efficiency=80 per cent.)*

$$\text{Watts Input} = \frac{3.65 \times 746}{0.80} = 3400.$$

5—Average current required during accelerating period at a line voltage of 1100 volts=34 amperes.

These calculations are based on the assumption of a constant or straight line acceleration curve from 0 to 1 200 r.p.m. The actual acceleration curve is steeper at start and then curves gradually to a horizontal line; hence the initial current will exceed 34 amperes by an amount practically proportional to the increase of steepness of the initial acceleration curve, if the rheostat resistance is correctly proportioned and the rate of cutting it out is uniform. If this is not the case, the current for part of the three seconds might greatly exceed the values calculated above, corresponding to an effort to accelerate at a higher rate than 400 r.p.m. per second. See article on "Relation of Flywheel and Motor Capacity" in the JOURNAL for March, 1912, p. 270. L. D.

1028—Inductive Kick of Motor Field —The field coil of a motor takes 0.58 amperes at 115 volts. It is connected with an ammeter having a one ampere scale in circuit and a voltmeter having a 150 volt scale across the terminals. The switch is opened so quickly that practically none of the electromagnetic energy of the field is dissipated in the break. What will the ammeter read the instant after the switch is opened? What will be the voltage across the voltmeter at this instant? Will either instrument

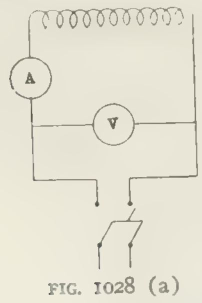

FIG. 1028 (a)

be deflected in the reverse direction? What is the highest resistance that should be connected across the field so that the potential across it cannot possibly exceed 150 volts when the switch is opened? T. F. (MASS.)

The general equation of the current in a circuit containing resistances and self-induction, and from which a constant potential E has been removed is

$$i = \frac{E - \varepsilon^{-\frac{Rt}{L}}}{R}$$

where i is the current at any time after the removal of E, R is the total resistance of the circuit, L the coefficient of self-induction and ε is the base of Naperian logarithms. This is practically the condition we have when the field current is discharged through a resistance. Assume that in this case the current flows through the field and discharge resistance in direction from A to B. It will be seen from the current equation that at zero time, or the instant after the break, the variable current i is equal to the constant current I. The voltage across any non-inductive part of the circuit of resistance r is, of course, equal to ri. When the switch is opened, an e.m.f. will be set up in the field coils which tends to maintain the current, and hence its direction across the discharge resistance will be from B to A and the voltmeter will be reversed, while the ammeter is not. The value of this current at the instant the circuit is broken is 0.58 amperes, and to keep the terminal voltage from rising above 150 volts the maximum resistance of the discharge circuit should be 258 ohms. The removal of the discharge resistance is equivalent to introducing an infinite resistance in its place, and if it were possible to open the switch so quickly that none of the energy stored in the field would be dissipated in the break, the voltage across the terminals would rise to infinity. The current equation at zero time would then be $i = I\varepsilon^{-\frac{\infty \times 0}{L}}$ in which the exponent is intermediate. For any finite value of t, however, the exponent would become infinite, and i would be zero. That means that the current would instantly fall to zero, and the rate of change of flux would be infinite. With a discharge resistance in the circuit the ammeter would read 0.58 amperes the instant after the break. With no resistance in the circuit, the current will immediately fall to zero, when the switch is opened, and the voltage generated will depend on the quickness of the break, the arc drawn, etc. It should be noted that in practice it would be impossible to obtain an infinite voltage, no matter how quickly the switch is opened. Even if no energy is dissipated in an arc or a spark across the switch, the rapid change of flux will set up secondary currents in the core and copper and the stored enegry will be dissipated. That the induced voltage may reach very high values, however, is shown by the fact that when a field circuit of even moderate capacity is suddenly broken, the insulation will often be found to have been punctured. K. L. H.

1029—Car Speed at Different Voltages —How can the speed of a car on any voltage be calculated. knowing the speed at some other voltage and the resistance of each motor, there being two motors? T. H. A. (NEW YORK)

Knowing the speed of the car on some particular voltage, in order to calculate accurately the speed of the car on any other voltage, it is necessary to have a train resistance curve from which the change in tractive effort required for changes in car speed may be calculated, and curves showing the speed-tractive effort characteristics of the motors with proper gear ratio and wheel diameter. For the present, assume that the tractive effort required to propel the car is not changed by the change in speed. Then the speed of the car when operating on the two voltages would be directly proportional to the counter or back electromotive-force of the motors. The counter electromotive-force of the motors on any given voltage is determined by subtracting the total drop in the motor from the applied voltage. This requires that the amperes load on the motors, and the resistance, must be known to get the drop. However, the tractive effort required does not remain the same, but increases as the speed increases. The speed increases as the voltage increases, so that with a higher voltage applied to the motors, greater tractive effort is required. Due to the speed-tractive effort characteristics of series motors (which are practically always used for traction purposes) the increased tractive effort is gotten at an increased ampere load. Thus, with a higher voltage and speed, the increase in tractive effort tends to keep the speed lower than it otherwise would be. If the train resistance and speed tractive effort curves are not available, the speed of a car on any voltage, when the speed on some other voltage is known, may be calculated approximately by assuming that the speeds on the two voltages are directly proportional to the applied voltage. The result gotten in this manner is usually sufficiently close for practical purposes, due to the fact that the change in tractive effort required partly compensates for the inaccuracy of figuring the speeds as being directly proportional to the applied voltage. The change in speed due to the change in voltage is not affected by the number of motors on the car. A. L. B.

1030—Power Readings in Three-Phase Circuits —What is the best arrangement for reading the current in three phases with two series current transformers and one ammeter? Would the readings be correct if the ammeter were placed in series with the wattmeter current wires? What are the advantages of three transformers? R. W. W. (IND.)

The customary arrangement is shown in Fig. 1030 (a). When the plug is not in the receptacle, the current transformers are short-circuited as shown. When any plug is inserted, the short-circuit is broken, as indicated by the cross and the connections are made as

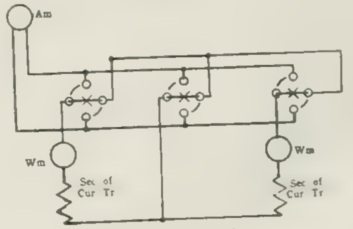

FIG. 1030 (a)

indicated by the curved lines around the receptacle. The accuracy obtained when ammeters and wattmeters are placed on the same current transformer depends upon the regulation and capacity of the transformer. Ordinarily this arrangement is entirely satisfactory where the load approaches the full capacity of the transformers for the greater part of the time, but when very great light load accuracy is demanded, separate transformers are ordinarily used. For the measurement of current only, there is little advantage in using three transformers. The wiring is somewhat simplified, but not sufficiently so to warrant the expense of an additional transformer. H. A. T.

1031—Exciter Trouble:—We have in our power house four steam turbines and two Corliss engines, all connected to alternating current generators of 9,300 kw total capacity, which operate in parallel and feed a load of about 160 induction motors. There were two motor-driven exciters of compound-wound non-interpole type which operate in parallel, and we have recently installed a new motor-driven exciter of the interpole type. This new exciter has a shunt on the series field, but neither of the old exciters have. We started the new exciter and put it in parallel with the other two on five alternating-current generator fields; the sixth generator was not running. All three exciters had very light loads, but the main generators were loaded about to capacity. About an hour later a 400 hp motor with a very heavy starting load, started. The engineer cut the rheostats out part of the way on both non-interpole exciters to hold up the alternating voltage, but did not touch the rheostat of the new interpole exciter. The alternating voltage dropped back farther than it usually does when this motor starts. A helper pulled the feeder switch to which this motor was connected. The alternating-current generator speeded up and the automatic stop on one of the turbines tripped and shut it down. As the other four could not carry the load the voltage dropped back and shut down all the motors. When we went to start up again we found that the polarity had been reversed in all three exciters and the fields had to be flashed before they would build up in proper direction. We have had shut downs before under similar conditions, but never had a reversal of polarity in exciters before. We naturally look to the new interpole exicter for the trouble. How do you account for the reversal of polarity?

O. R. S. (WEST VIRGINIA)

The fact that the alternating voltage of the system was lower after the new exciter was installed is, doubtless, accounted for because the new exciter series field, together with the shunt, had the effect of shunting a certain amount of the series field of the old exciters. The compounding of the entire combination of exciters then would be reduced with the result that the alternating voltage would not be held up in the same manner as before. When the alternating voltage dropped back on account of the heavy load, the motors driving the exciters began to slow down and the field from the alternating-current machines probably discharged through the exciters, and in so doing the armature current would be in the same direction as when the exciters were acting as generators, but the shunt field current would be reversed and this would consequently reverse the polarity of the exciters.

D. H.

1032—Ground Detector—Will you please tell me how to read a three-phase electrostatic ground detector; that is, the position the index hands will assume when there is a ground on either phase, and also various grounds from a partial to a dead ground?

R. E. L. (OHIO)

An electrostatic ground detector depends for its operation on the attraction which exists between two plates slightly separated from one another and between which a difference of potential exists. In the single-phase meter indicated in Fig. 1032 (a), so long as both lines A and B are at an equal potential above ground, plates F and G attract plate E equally and the pointer remains in the neutral position. If line A becomes grounded, no potential difference exists between plates E and F, and the attraction between parts E and G draws the pointer towards the right. The same general conditions hold true in the case of a three-phase ground detector indicated in Fig. 1032 (b). In this case, if line A becomes grounded no potential exists between plates E and F with the result that plate E is attracted equally towards plates G and

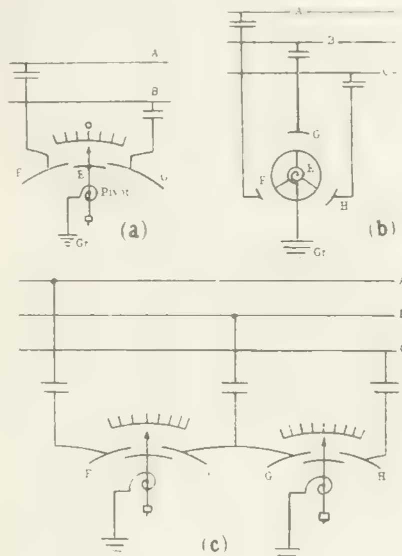

FIG. 1032 (a), (b) and (c)

H. In both the single-phase and three-phase instruments it will be noted that the pointer moves away from the line which has become grounded. In the case of two single-phase meters on a three-phase system, as illustrated in Fig. 1032 (c), a ground on the left-hand line will cause the pointer of the meter on the left to deflect toward the right. A ground on the right-hand line will cause the pointer of the meter to deflect toward the left. A ground on the center wire will cause the pointers of both meters to deflect away from the center.

S. M.

1033—Loading Back Two Similar Transformers.—Two transformers were operating under normal conditions, except that the voltage and current in transformer No. 2 are slightly different from those in No. 1 on account of the impedance of the loading transformer and the opposition of load and magnetic currents, as shown in Fig. 1033 (a). The points A and B being at the same potential, except for the line drop A to B. Why does all or a large proportion of the circulating current go through transformer No. 1 and not divide between No. 1 and the magnetizing transformer? The transformers being connected together on the high tension side, it seems as if this makes the low tension current the same in both transformers, yet in one transformer the magnetizing and load current are in the same direction, and in No. 2 these same currents are opposed. How is this possible when the high tension circuit is a series arrangement? Is it possible for the load or circulating current to oppose the magnetizing current and still have the transformer operate?

With a scheme of connections as shown in Fig. 1033 (a), it is practically impossible for the circulating current to divide between transformer No. 1 and the magnetizing transformer. Fig. 1033 (b) is a modified sketch, and from this arrangement, transformer No. 2 tends to govern the circulating current in transformer No. 1. If the magnetizing transformer was disconnected and a short-circuiting lead connected across leads BE, the circulating current would still pass through the winding BE, and the only current passing through the short-circuiting lead would be the magnetizing component of the circulating current, which is practically negligible. The total impedance voltage applied to BC would then exist

FIG. 1033 (a) and (b)

across DC and the impedance voltage of transformer No. 1 would exist across the high tension terminals GH. With the transformers connected as shown in Fig. 1033 (b), the current in winding BE will be equal to the vector sum of the circulating current of transformer No. 1 and the magnetizing current of both transformers, transformer No. 2 being magnetized on the high tension side through transformer No. 1. This is a condition equivalent to having the vector sum of the magnetizing and circulating currents in the low tension of transformer No. 1 and the vector difference of the magnetizing and circulating currents in low tension of transformer No. 2. Since the scheme of connections shown in Fig. 1033 (b) indicates that the magnetizing and circulating currents are obtained from the same phase and source of power, it is evident that the low tension voltage of transformer No. 2 is equal to the arithmetical difference between the magnetizing voltage FA and the impedance voltage BC. If either load or magnetizing leads were crossed the conditions would be just the opposite, and transformer No. 2 would have the greater voltage and current. If the magnetizing transformer was connected to a different phase than the loading transformer, the voltage across the low tension of transformer No. 2 would be the vector sum of difference of the magnetizing and impedance voltages, depending upon their relative directions; it being possible in some cases to have practically balanced voltage and currents in high and low tension windings in both transformers. This method is regularly employed in making loading back tests on all transformers.

W. F.

1034—Unsteady Voltage—We have a 100 kw, 225 volt, 280 r.p.m., 6 pole, commutating pole generator driven by a tandem compound engine and controlled by a Tirrell voltage regu-

lator. The load includes lights and elevators at the same time. The lights flicker badly and the regulation is poor. (a) Must a generator work low on the saturation curve in order to work well with a regulator? (b) Will changing the length of the air-gap have any effect? (c) Will removing the German silver shunt from the series field be of any benefit? The compounding is now flat, 60 percent of the current being shunted. (d) Would an inductive shunt be worth considering? (e) The elevator load varies from 100 to 400 amperes. When it is reduced the voltage rises from 225 to 240 volts and takes considerable time to return to normal, this being apparently due to residual magnetism and a slight increase in engine speed. Would good laminated poles remedy this or will increasing the air-gap help any? (f) What can be done to increase the effectiveness of the regulator? W. F. L. (CALIF.)

(a) Low magnetic saturation is desirable for machines operating with regulator, as the voltage responds much more rapidly to the exciting current variation. (b) The length of air-gap will have little or no effect on the voltage fluctuation caused by the elevator load. (c) No. (d) No. (e) Without knowing the general design of the machine, it is impossible to say whether laminated poles would help appreciably. (f) It is impossible to prevent momentary voltage variation and lighting flicker on a circuit which also carries a large proportion of elevator load. As the most satisfactory solution of the circumstances cited, we would advise the installation of an entirely separate generator for the lighting circuits; as, aside from this, the irregular voltage variation would not be of serous moment for elevator load only. R. H. T.

1035—Commutator Trouble—We have in operation a 475 kw, 300 volt, 127 r.p.m. direct-current engine type generator direct connected to a cross-compound Corliss engine. The engine shaft is not central with the outside of the armature core, which is noticeable when the engine is running slow. With the engine running at full speed and the generator loaded, the armature seems to run still more out of true, this being due perhaps to the field pull. Starting with the commutator perfectly true, the brushes, which are of the radial type, move about 1-32 of an inch when the machine is loaded. What effect would this have on the commutation? We have considerable trouble with "flats." Would this cause it? The load on this machine is steady, being electrolytic. The armature has no balance rings. J. F. J. (MICH.)

It is not likely that the brushes can follow the commutator with a movement of 1-32 inches and as the brush leaves the commutator there will be sparking. This sparking will probably be worse in some brush arms than in others and will occur once per revolution. This action will burn the commutator and flats will probably result. D. H.

1036—Temperature of Electric Heaters—What temperature is generally attained by the heating element in toaster stoves, percolators and electric irons? S. H. C. (IND.)

The temperature in these devices varies greatly, depending upon the design. For designs in which mica is used to insulate the heating element, the temperature may range anywhere from 500 to 700 degrees C. B. A. B.

1037—Capacity of Testing Transformer—In testing a 600 kilowatt, 2 200 volt generator with double voltage to ground, using a two kilowatt transformer, should the current in the low voltage side of the transformer be simply the magnetizing current? How much of an increase of current would be considered as indicating a serious weakness of the insulation? R. M. (NEW HAMPSHIRE)

The current in the low voltage side of the transformer will be the vector sum of the exciting current of the transformer, and the charging current due to the electrostatic capacity of the apparatus being tested. In the case referred to, the charging current should be a negligible quantity. The numerical value of current in the low voltage side of the transformer cannot be taken as a measure for the dielectric strength of the apparatus being tested. If the two kilowatt transformer used in making the insulation test had a normal voltage rating of 2 200, but was worked at double voltage and normal frequency, there would be an excessive current in the low voltage side, since the transformer iron would be worked at double its normal magnetic density. W. J. H.

1038—Rating of Alternators—The capacity of a generator being governed by the temperature rise in its different parts, what is the percentage difference in capacity, if any, between two generators rated as follows? (a) The generator will have a capacity of delivering 750 kva or 600 kw at 80 percent power-factor at 2 300 volts, 188 amperes per terminal, with a temperature rise not to exceed 50 degrees C. above the surrounding atmosphere in any part. (b) The generator will have a capacity of delivering 750 kva or 750 kw at 100 percent power-factor at 2 300 volts, 188 amperes per terminal with a temperature rise not to exceed 50 degrees C. above the surrounding atmosphere in any part. If each machine is designed to operate under the conditions named, will there be any difference in the rise in temperature if (a) operates as (b) and vice versa? In other words, will any difference be required in the excitation of the machine, which would allow one to carry a heavier load than the other? E. M. S. (MO.)

With full-load 80 percent power-factor on a modern alternating-current generator, the required excitation is in the neighborhod of double that required at the no-load normal voltage condition, while at full-load, 100 percent power-factor, the excitation is slightly in excess of the no-load excitation; also, the temperature of the armature is affected slightly by the field temperature, due to radiation. With the 80 percent power-factor generator operating at 100 percent power-factor, the field temperature would be considerably decreased and the armature temperature slightly decreased. With the 100 percent power-factor generator operating at 80 percent power-factor, the field temperature would increase excessively and the armature temperature would slightly increase. In all probability the excitation volts for this condition of operation would be greater than the available supply and hence the terminal voltage of the 100 percent power-factor generator would drop below normal. In other words, the generator designed only for 100 percent power-factor could not be operated satisfactorily at lower power-factors with only normal exciting voltage available, as a properly designed 100 percent power-factor, 50 degree alternating-current generator requires less excitation than a similarly designed 80 percent power-factor generator. It is evident that the 80 percent power-factor generator has a greater capacity in that it can carry greater low power-factor loads than the 100 percent power-factor generator. R. K.

1039—Transmission Data—On a three-phase, three-wire, 60-cycle transmission line with the wires spaced 24 inches apart. (a) Does the voltage loss vary directly with the distance? (b) Does the voltage loss vary directly with the kw or the kva? (c) What formula is used to determine this voltage loss? (d) Considering a line of the above description connected to a 13 200 volt alternator using No. 2-0 copper wire, what is the voltage loss per mile per 1 000 kw? L. J. H. (N. J.)

(a)—Other conditions being equal, the voltage loss varies directly with the distance. (b) — Other things being equal, the voltage loss varies with the kva rather than the kw carried. (c)— See articles on this subject by Ralph D. Mershon, Clarence P. Fowler and Chas. F. Scott, in the JOURNAL for 1907, March and April, pages 137, 152 and 227. (d)—From tables given in the articles mentioned above the voltage drop per mile per 1 000 kw, three-phase, assuming a power-factor of 80 percent, would be approximately 66 volts. For a more elaborate treatment of the question we recommend "Transmission Line Formula," by H. B. Dwight and "Practical Calculation of Transmission Lines," by L. W. Rosenthal. C. R. R.

1040—Current Collection—(a) What are the causes of cutting of collector rings and commutators when copper brushes are used, and how may such cutting be prevented or minimized? (b) What are the usual pressures in pounds per square inch used with carbon brushes on commutators in machines of all sizes? J. C. C. (CALIF.)

(a) Cutting with metal brushes is obviously due to the friction of the hard brush on the relatively softer collector ring. It can be greatly decreased, if not entirely eliminated, by proper lubrication. Lubrication with vaseline or similar greases by hand will do some good, but the best results have been obtained by adding insulated lubricating brushes to each ring. While ordinary soft graphite blocks are often used for such lubricating brushes and are sometimes effective, the best device we know of is the Schweitzer Lubricating Brush which is essentially a compression grease cup. A special elastic lubricant is used with which only occasional attention is required. (b) Brush pressures vary over a wide range for different classes of machines. Railway motor brushes require much heavier pressure than others, four to six pounds being common practice. Large stationary generators and motors require much lower pressure, one and one-half to two and one-half pounds representing good practice. The newer, high capacity, soft brushes require relatively low pressures. F. D. N.

THE ELECTRIC JOURNAL

VOL. XI — MARCH, 1914 — No. 3

Turning the Wheels of Industry

In nearly all industries the scheme of production involves the utilization of certain amounts of mechanical energy. The particular arrangements as to the method of supplying power are almost as numerous as the industries themselves. It has thus come about that the study of the best means of providing mechanical power in each industrial operation has been given serious attention by many engineers, both among those interested in the products of the industries and those interested in the providing of means of supplying power. The present issue of the JOURNAL is devoted almost exclusively to discussions on the application of electric power to various industries, as have been the March issues for several years past. While numerous types of applications are here discussed, the variety and extent of modern industrial operations are so great as to make possible only the selection of a limited number of the more typical applications.

The subject of motor drive may be considered,—first, from the viewpoint of the individual industry; second, that of the power company; and third, that of the manufacturer of motors and accessories

From the standpoint of the motor manufacturer it would undoubtedly be desirable to have all operations requiring power performed by a single line or type of motors of appropriate ratings. Progressive manufacturers, however, recognize that there are particular requirements in many industries which may make desirable or necessary the use of motive power having characteristics especially adapted to the particular work in hand. In some instances the need is for constant speed, in others for large speed range. In some industries absolute reliability under extremely severe conditions is essential, in other applications portability or small weight per unit of output is important.

From the standpoint of the power company there is the desire for increased business. At first there was merely the thought of the greatest possible connected load, but modern power companies now scrutinize prospective loads carefully, not only as to the probable total kilowatt-hours to be used per annum, but as to the characteristics of the incoming load. Among the factors to be considered are the maximum demand, hours use per day and seasonal use, diversity factor, power-factor, etc.

When the question of motor drive is discussed by industrial concerns, there are many features to be considered, some of an economic rather than an engineering nature. The manufacturer is accustomed to operating his plant under certain conditions. In some cases electric drive can be introduced without material modification in the scheme of production, in which event the question of the advisability of adopting motor drive is largely one of relative power costs In other industries the introduction of the motor opens up entirely new possibilities in the way of manufacturing arrangements and rate of production. In such cases the matter of relative power costs of two methods may be entirely overshadowed by the possibilities of increased production or improved product.

A careful review of the various articles in this issue will bring out the determining features in each class of application. In irrigation pumping, for instance, the motors must operate with a minimum of attention; they form a very desirable load for power companies, and the rancher can determine, by comparison with previous records, just how much profit is secured by the use of electric pumps.

For planers, motor manufacturers have developed special motors with small rotative inertia and special control features in order to make a complete unit without the necessity for the usual crossed belts. In this application, the power company is not particularly interested as to whether the planer is driven with or without belts, but the users of such machines find great relief due to the elimination of belting and refinements in control made possible by direct drive with motors especially designed for the purpose. Similarly special motors have been developed for the drilling of oil wells with resulting benefits to all concerned.

In laundries and paper mills it is usually possible to make use of fairly standard motors of moisture-proof construction. The power companies find such concerns rather difficult to secure as customers, owing to the large amount of steam and hot water required for other than power purposes. The owner of an electrically operated laundry finds in the motor a convenient source of power in small units so that he can drive each machine when and as needed, and at its proper speed, without interfering with other operations. An inspection of two laundries, one of the old fashioned engine-driven type and the other of the electrically-operated type, forms a most convincing example of the advantages of using electricity.

These few instances will serve to indicate the great diversity of work now being performed electrically and the necessity for discussions, such as given in this issue, indicating the peculiar power requirements of each industry.

Motor Drive in the Industrial Field

C. W. DRAKE

PERHAPS the most remarkable feature of the use of motor drive for industrial purposes is the extraordinary rapidity with which it has been generally adopted. Fifteen years ago an electric motor was a rarity in an industrial plant. A few far-sighted men were using this drive for general purposes, and others found the motor especially desirable for certain specific purposes, but these applications formed conspicuous exceptions. In general, men of the industries had no use for the motor. The drives they were using were apparently satisfactory and represented what engineers and practical men had found to be best after many years of experience. If the plant was making money, what need to change? If it was not, the cost of installing motors was prohibitive.

But today, in spite of the extreme reluctance—not to say strenuous opposition—on the part part of the industrial managers themselves, motor drive has swept the field. There is not an industry where it is not used to some extent; there are many in which the majority of machines are motor-driven; and, in most, motor drive is recognized as the most satisfactory and economical drive, provided electrical energy can be secured at a reasonable cost. The rapidity and completeness with which this revolutionary system has been accepted is without parallel in industrial history and is only comparable with the triumph of electricity in other lines, such as traction, illumination and the transmission of intelligence.

Obviously there must be some strong, convincing reason why an event of this kind has taken place and this reason can be summed up in the word "economy," or rather, "increase in profits," because motor drive not only saves money but helps to earn more money. Motor drive has pushed its competitors aside simply because it can do its work more cheaply and satisfactorily than any other known means.

If the average engineer who has not made a special study of motor applications were asked the question, he would undoubtedly say that the reasons why motor drive is economical are practically the same for all industries, and that this economy arises from the fact that electrical energy can be transmitted and utilized where needed with greater efficiency than any other kind of power. He would also point out that, by eliminating belts and line shafts, a considerable saving in energy consumed, and consequently in fuel, would result.

These are indeed the fundamental reasons for the use of electric power in many plants and, being the obvious ones, have been accepted by many as the only ones to be advanced in favor of motor drive. But as a matter of fact, a close study of the various industries discloses many other advantages of equal or greater importance.

To show in what class of plants the various advantages of electric drive are most evident the manufacturing conditions of the different industries can be compared in a general way.

Mechanical layouts may be classified as follows:—

- Mechanical Layout
  - Small
    - Complex
      - Low load-factor
        - No steam required
        - Steam required
      - High load-factor
        - No steam required
        - Steam required
    - Simple
      - Low load-factor
        - No steam required
        - Steam required
      - High load-factor
        - No steam required
        - Steam required
  - Large
    - Complex
      - Low load-factor
        - No steam required
        - Steam required
      - High load-factor
        - No steam required
        - Steam required
    - Simple
      - Low load-factor
        - No steam required
        - Steam required
      - High load-factor
        - No steam required
        - Steam required

By "large" is meant installations over 100 horsepower. "Simple" and "complex" refer to the number and arrangement of buildings, shafting, and the machines in each building. "High load-factor" is considered as being above 15 percent for a 24 hour day. Steam requirements refer to those for other than power generation.

When this tree is inspected for those plants in which electric drive is most desirable, it is found that a small plant, complex in layout, with a low load-factor, and not requiring steam for manufacturing processes, such as a small wood working plant or machine shop, lies at the upper limit, while a plant of large size, simple in layout, with a high load-factor, and requiring steam for its operation, such as a large distilled water ice plant, lies at the lower limit. Theory and practice both show that in the upper range lie the greater number of prospective users of motor drive and also those that are most easily converted to its use. These classes are likewise those that the power solicitor should first cultivate, since, being small and having a low load-factor, they cannot generate power economically and in most cases they operate off-peak. Of these plants, therefore, nothing further need be said.

Although plants of the lower class are apparently poor prospects for motor drive, there are many plants in this class which are adopting motor drive primarily to make use of central station service. By this means it is possible to eliminate entirely the power house equipment. As an extreme example of a plant in this class, we might have an engine in one

room coupled to a shaft driving a few large machines in the next room, and it is evident that under these conditions the advantages of motor drive can be fully realized only by the use of central station power. In order to show more clearly how various industries line up according to the above classification, and also how the various characteristics of motor drive contribute to the success of the installation, the following examples are given:—

Small rubber plants may be placed among the lower classes, yet these plants are rapidly installing motor drive, and using central station power where it is available. Rubber-mixing mills will average about one horse-power per inch width, so that in a small space it is possible to consume several hundred horse-power. Constant speed is required for the mills, but for the calenders, adjustable speed over a range of three or four to one is of great value. Mechanical gear-changing devices giving two speeds are in common use, but even very small rubber plants have found that by having a wider and more easily adjustable speed control, the production can be increased about 25 percent. In one plant, for instance, which had about a dozen calenders and was unable to obtain the desired production, the installation of electric motors not only enabled a greater production to be obtained, but left two calenders idle for still further production. Such an increase alone pays liberal dividends on the electrical equipment necessary, and reduces the number of calenders required for a given production.

In a cement plant, power is also used in large units that can be assembled in a comparatively small space. Constant speed is required for over 95 percent of the load and yet motor drive shows a large saving. One prime reason is that cement dust and oil is a bad combination for line shaft bearings, belts, and power house equipment. Also, no cement plants work continuously at maximum capacity, and with individual motor drive, the power consumed is almost exactly in proportion to the output, which is far from true with line shaft drive. Economy of power is of great importance in a cement plant since power is a very large proportion of the total manufacturing cost, about 20 kw-hr. per barrel of cement being required on the average.

Paper mills range near the bottom of the scale, require considerable steam, and are usually of rather complex layout. Practically uniform speed and ample power at each machine, which can be obtained by motor drive, have greatly increased both the quality and the quantity of pulp and paper manufactured. One plant, which was driving its paper machine through a variable speed cone from a water wheel shaft, decided to install an adjustable speed motor on the machine, supplying it from a direct-current generator driven from the water wheel shaft. The greater ease of control, together with the better speed regulation, improved both the quality and the quantity of the paper produced, and fully warranted the expense.

An investigation of the equipment in a plant that manufactures show-cases proved that the engine was fully loaded but that about 65 percent of the load was friction. The drives were very complex, and the load-factor low. Electric drive was adopted, using over a hundred squirrel-cage induction motors, and installing a generator on the engine. After this change there was ample power available to supply an addition to the plant of nearly 25 percent of its original capacity. Besides this, the maintenance of high speed at all of the wood-working machines not only increased the capacity of the plant, but gave a much better finish to the material, thus saving considerable sanding.

Textile mills are usually very complex and have a high load-factor, so it would be expected that a great saving might be made in the power required. Energy can be saved in most cases, but the cost of the product is so high in comparison with the cost of power that a saving in power amounts to little, whereas even a slight increase in the output warrants a considerable investment in equipment. This is especially true in silk mills, and in one case, where it was found that the saving in fuel effected by the use of motor drive was almost negligible, it was also found that an increased production of nearly 15 percent was obtained, the value of which paid royal dividends on the investment required. In mechanically-driven textile mills there are pulsations in the speed of the shafting, due in part to the cyclic variations in the engine speed but more to the variations caused by changing load on the machines connected to the shaft. Motor drive gives a constant speed and a higher average speed than is possible with line shaft drive, and it is due principally to this fact that the greater output is obtained. Cleanliness and the elimination of "seconds" caused from oil dropping from overhead shafting, is an item which in itself practically warrants the installation of motor drive.

The above instances show how one feature of motor drive may be the controlling one in one plant, and of comparatively small importance in another. In one plant the adjustable speed gives the increased production, and in another the maintenance of constant speed. In one it is the elimination of complex shafting and friction, while in another it is simply the elimination of the power plant that recommends the use of motors and purchased power.

Irrigation by Pumping in California

R. A. Balzari

THE LARGE AREA, together with the diversified climatic conditions in California, makes this State one of the best for the study of the irrigation problem. From the orange groves in the Southern part of the State, through the San Joaquin and Sacramento Valleys, to the plateaus of Siskiyou, there is a variation of land, water and climatic conditions which is equal to any in the world. This diversity of conditions has developed many methods of irrigation.

The water table varies over wide limits, from pumping heads in certain sections of from four or five feet, to other sections where the head is as high as two hundred and fifty feet. Due to this variation in pumping head, a study of the land conditions and water table at different points must be made, in order to insure getting sufficient returns from the land when irrigated, to warrant the expense of obtaining water at that point. In sections where the pumping head runs up as high as one hundred to one hundred and twenty-five feet and the amount of water is limited, the production of both deciduous and citrus fruits is carried on most extensively. As the yield of fruit per acre is high, a high expense for irrigation is allowable. Although this land is very rich and would produce alfalfa in large quantities, the cost of irrigation for alfalfa would be as great as the returns from its production. In the low land regions, where the water table is very close to the surface and the pumping heads range from the ten to fifty feet, alfalfa can be produced in large quantities and with good returns on the initial investment.

These conditions have led the power companies, together with the manufacturers of electric motors and pumping machinery, to make a careful study of the land, water and climatic conditions throughout the State, in order to give proper advice to the farmer both in the original purchase of his land and the class of irrigation which he should attempt to carry on in that particular section. The irrigation of this State has been greatly developed also by real estate concerns which have improved tracts for placing on the market.

The problem of irrigation by pumping may be divided as follows:

1—Improving the productive possibilities of land which had been farmed for a great length of time.
2—Developing land which heretofore was practically arid due to insufficient rainfall.
3—The reclamation of land which was a waste area, due to the presence in the ground of different classes of alkali.
4—The placing of individual pumping plants in systems where gravity irrigation has been carried on for a number of years.

GRAVITY IRRIGATION SYSTEM

Certain portions of the State have long enjoyed the privileges of a gravity system of irrigation. Most of these systems, however, are fed either by rivers or reservoirs where the winter rainfall is stored, and consequently during the latter part of the summer, the water supply becomes very limited. The development in all districts where gravity systems of irrigation prevail, has been very rapid and the land has always maintained a high valuation, due to the greater production available through means of irrigation.

When the electric power companies began to extend their transmission lines into these districts, particularly where water was obtainable within twenty to fifty feet of the surface, they began to advocate the use of individual pumping plants, thereby making the farmer independent in his operations. The hardest problem is to show the farmer exactly where he would gain by having his own individual pumping plant. It is found, however, that even on a gravity system, a man can frequently install his own individual plant and operate it to better advantage than he could take water from the gravity system which is in operation at that point.

One of the principal advantages in having an individual plant is the fact that water is available just at the time desired. On the gravity system, it is necessary for each person to take the water as his turn comes, and if his land is not ready at the time the water is due, it is probably necessary to wait from ten to fifteen days, in order to irrigate his land. This may be the cause of reducing that particular crop very materially, as in alfalfa a loss of from one half to one ton per acre may occur. Therefore, it is easily seen that by having an individual plant, and being able to put the water on the ground exactly when the ground is ready for it, the maximum returns can be obtained from the land.

The cost of operating an individual plant or obtaining water from an irrigation system is practically the same, so that there is no particular gain, in most instances, from the cost of irrigation standpoint, in a man having his own individual installation. In very low head work, the individual plant can be operated very cheaply.

A third consideration, however, which is a most important one, comes into this selection of an individual plant versus the gravity system and that is the question of fouling the land. All gravity systems have long canals before they get to the farming community where the water is used, and along these canals, in most cases, is waste land that cannot be used for any class of cultivation. Consequently, there are weeds of different character growing on this waste land which, during seed time, blow into the canals and are given the direct water transportation route to the farm lands in the lower country where the water is being utilized. A careless neighbor may also

allow weeds to grow on his land and blow into the distributing ditches, which will be transmitted to every one on the ditch below his ranch. This is not the case where a man has his own individual plant. One ranch in the interior, where the land was fouled by Napa thistle, was so badly seeded during one season

FIG. 1—POMONA DEEP WELL DOUBLE-ACTING, SINGLE CYLINDER PUMP

Belted to a ten horse-power induction motor. This pump delivers 160 gallons per minute over a total head of 150 feet.

that it took four years to entirely remove the thistle, and, in fact, required the reseeding of the land, which amounted to at least ten dollars per acre; in addition to which there was the work of cutting out the thistles and the partial loss of production of the land. Another type of fouling is of the much dreaded fox-tail in districts where alfalfa is grown. This weed can practically be eliminated from a ranch that has its own individual water system. It cannot, however, be kept off of land that is worked under a gravity system, due to the fact that it grows very rapidly and also will grow on any class of land. These considerations have led to the installation of over 3 500 horse-power in pumping motors in the district of Woodland, Yolo County, although they have one of the best gravity systems in the State.

FURTHER DEVELOPMENT OF PRODUCING PROPERTIES

There is a large area in California which, before the days of pumping, was planted in orchards. The return from these orchards was large when the year was good, but in the case of a dry season, the crop would hardly warrant the picking. The farmer took this as a matter of course, and in the lean year lived on the results of past labors. When the hydro-electric power plants sprang into being, it was necessary to find a market for their surplus power, and they proceeded to develop the pumping possibilities in lands which were not favored with the gravity system of irrigation, or where they were not favored with the rainfall which was necessary for [illegible]. The fact that the farmer leans towards the idea that "what father has done, is good enough for me," made it difficult to convert him to the possibilities of orchard irrigation, and made necessary the installation of demonstration plants in many districts, proving that water was available in sufficient quantities to warrant installing a pumping plant, and also that when the water was applied to the land, the results obtained would justify the expense of an installation. Several years of consistent work have proven that water applied at the proper time to trees or vines will give, not only increased production but better fruit.

In the Santa Clara Valley, known as the home of the prune, even in years of normal rainfall, it is found that by scientific irrigation the quantity of prunes can be increased from twenty to forty percent and the quality from 60-70 grade to a 30-40 grade. At the time of writing this article, 60-70 grade prunes were quoted at six cents per pound, while the 30-40 grade was quoted at seven cents per pound, in San Francisco.

Through this particular Valley, the pumping is done ordinarily with deep well pumps. This is made necessary by the fact that the water table varies from fifty to seventy-five feet in depth, and also that it is obtainable only in limited quantities. Figs. 1 and 2 show two different types of pumps that are installed in this particular work.

It is found that water applied to almond trees during the early summer will prevent the much

FIG. 2—BYRON JACKSON TURBINE PUMP

Direct connected to a 15 horse-power, 1 135 r.p.m. vertical induction motor. This pump delivers 560 gallons per minute at 70 foot head.

dreaded "stick tight," the stick tight being an almond on which the shell does not loosen when the almond has become thoroughly ripened. One ranch in particular affords a chance to compare the effect of scientific irrigation during the years of 1911, 1912 and 1913. The rain falls during these three years were prac-

tically the same in amount and the time in which they fell. In 1911, a forty acre farm planted to almonds, depending entirely upon rainfall for the irrigation, had forty percent of the total production result in stick tights. This stick tight, of course, is not an entire loss, but means increased cost of handling and is undesirable from an almond grower's point of view. In the Fall of 1911, the owner of this ranch installed a 15 horse-power induction motor, direct-connected to a seven-inch centrifugal pump. This plant was pumping over a total head of twenty-two feet from a small creek which ran adjacent to the ranch. The complete pumping installation, being of a simple type, cost about $1 250 installed. As soon as the plant was finished, in December, 1911, the owner gave the ground around his trees a good wetting, putting on about ten or twelve inches of water per acre. He did not irrigate again until in June of 1912. At that time he made another irrigation of these trees, putting again about ten or eleven inches of water on the ground. The increase of crops was about thirty-five percent over that which he had obtained before and,

FIG. 3—TYPICAL PUMPING PLANT AND CONCRETE DISCHARGE BOX

in addition to that, he had only one percent of stick tights in the total production. In 1913, similar irrigation was carried on and the results were practically a duplication of what he received during the year 1912. Considering that almonds range in price from ten to fifteen cents per pound, it is seen that even a small increase in production very materially increases the profits of the land.

Similar results have been proven in the culture of peaches and apricots. In the district of Yuba City in Sutter county, this development in quality and quantity of peaches produced has been repeatedly proven. On one thirty-acre tract in particular it was found that the increased amount of production on an orchard by irrigation was forty-two percent. The quality was very materially increased, so that instead of getting a peach of one and one-half or two inches in diameter, peaches running from two and three-quarters to three and one-half inches in diameter were obtained. The irrigation of peaches, however, must be watched very closely, due to the fact that too much water applied to the ground late in the season will cause a watery peach of very low percentage of sugar, so that although the peach will be large and will grow in large quantities, the quality will be so low that, for canning purposes, the market value decreases very rapidly.

The amount of water pumped per season for the above classes of production varies with the land that is being irrigated. On the heavy soils, where fruit and nuts are produced, from fifteen to thirty inches of water are used. On the light soils as high as forty acre-inches per season are pumped. All of this water does not reach the land, due to loss by seepage and evaporation.

DEVELOPMENT OF NEW LAND

The above heading is not exactly correct, because the land which has been developed by irrigation has been farmed for a great number of years for grain. Most of the land in this State was formerly used for dry farming. The value, however, has been increased very materially, and the character of production of the land has been changed.

In sections of this State where the water table runs from 15 to 40 feet in depth, the raising of alfalfa and sugar beets has gone forward very rapidly. A typical pumping plant with a concrete discharge box, as used in the alfalfa and beet districts, is shown in Fig. 3. The building covers a 75 horse-power induction motor, direct-connected to a twelve-inch centrifugal pump, which delivers 4 000 gallons per minute over a pumping head of forty feet. There are 600 acres of land planted to alfalfa and 500 acres to sugar beets. Last year the production from 100 acres of alfalfa land was over 800 tons. The production on the beet land averaged eleven tons per acre. The pumping plant operated for one hundred and eleven days, consuming 184 000 kilowatt-hours during this time. The water is obtained from six wells located in a straight line and with twenty-five foot centers. The pull down on the pump is twenty-seven feet, the pump and motor being located in a pit, seventeen feet below the surface. The friction loss in the pipe is rather high, due to the long suction pipe required and the number of turns. The increase in valuation of this land may be considered on the following basis:—

When producing grain, for which it was formerly used, this land was valued at $75 per acre and produced, in an average year, about twenty sacks, which could sell at the rate of $1.50 to $1.75 a sack, making a total production per acre per year not to exceed $35. The land is now worth from $150 to $250 per acre and returns in alfalfa from $95 to $125 per acre during the average year, and the return on beets will run $60 per acre.

By raising cattle on alfalfa land, the increase per acre is much greater than by simply raising the alfalfa and marketing it direct. Thirty head of stock can be raised on twenty-two acres of land. Besides this, numerous chickens and hogs can be raised on by-products from the dairy industry.

Another notable instance of the land develop-

ment is that brought forward by the Sacramento Valley Irrigation Company, who are developing over 150 000 acres, under one master system, by taking the water from the Sacramento river by vertical turbine pumps, elevating it over a head varying from one to seven feet, and using the gravity system from this

FIG. 4—MAIN PUMPING PLANT OF THE SACRAMENTO VALLEY IRRIGATION COMPANY

point on. The main pumping plant, shown in Fig. 4, is comprised of four vertical turbine pumps, particularly designed for low head operation, geared to 350 horse-power 435 r.p.m. vertical motors. The motor speed is reduced by gears to give a speed on the pumps, ranging from 40 to 60 r.p.m., the speed changes on the pumps being made by changing the pinions. The capacity of this plant is 900 second-feet. The land under this project is being developed for both fruit and alfalfa.

The Mills Orchard Company are planting 4 000 acres of the foot hill region in the lower end of the

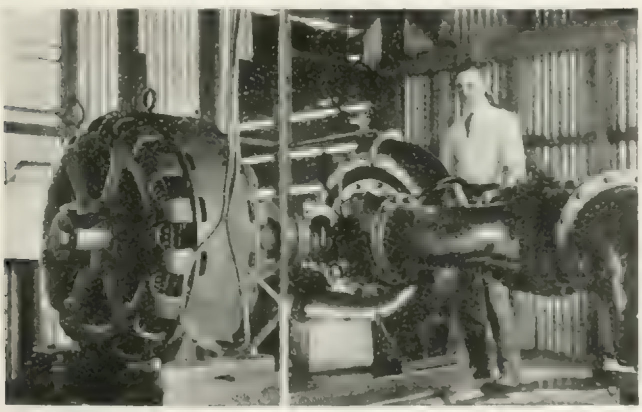

FIG. 5—ONE HUNDRED AND FIFTY HORSE-POWER INDUCTION MOTOR

Direct-connected to a 12 inch centrifugal pump on the Mills Orchard development.

Sacramento Valley Irrigation Company's project in lemons. This production introduces the high head irrigation feature which is warranted by the large returns in lemon production. The No. 1 plant of this orchard development is shown in Fig. 5. This pump delivers 4 000 gallons per minute at a total pumping head of seventy feet. The suction head is about four feet, the water being taken directly from the irrigation canal. Water is delivered at the seventy foot level and taken by gravity ditches to three other plants on this level. Five and six inch pumps at these plants pump into the distribution lines. Fig. 6 shows the concrete stand-pipe used in this distribution, and shows the character of trees and the method of irrigation. The pumping heads on these plants will vary from 100 to 250 feet, depending on the point at which the irrigation is taking place.

The hills which were a few years ago used only in grain culture and valued at about $10 or $15 per acre are now covered with beautiful lemon groves. When the lemons are brought into bearing the land will increase in value to from $1 000 to $1 500 per acre. This development is made possible by the available electrical energy at a reasonable power rate. This company also grows their own nursery stock, and at the present time has the largest nursery of

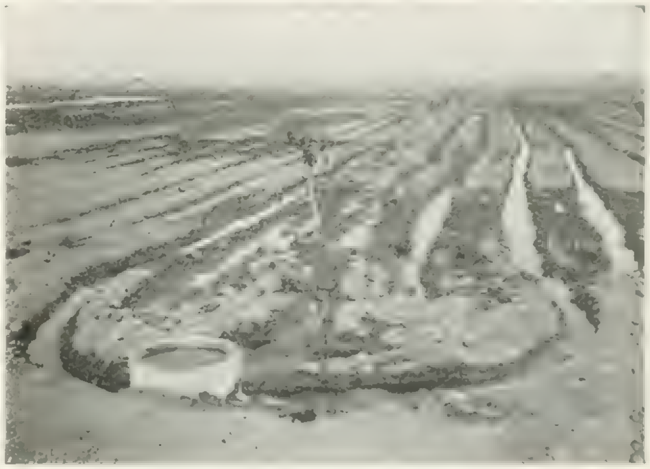

FIG. 6—CONCRETE STANDPIPE USED IN CONNECTION WITH WATER DISTRIBUTION BY THE ORCHARD MILLS COMPANY IN THE SACRAMENTO VALLEY

seedling lemon and orange trees in the world. They have over three million trees at the present time, which will be planted during the coming season.

ARID LAND DEVELOPMENT

In the interior of the Sacramento Valley there is a tract of approximately thirty to forty thousand acres of what is known as "goose land." This goose land or, in other words, alkali land, has a surface soil which is very heavy with sodium sulphate and sodium bicarbonates. the presence of the salt in this land being due to poor drainage. The land, itself, is very rich, being of alluvial nature, and when the salts are removed, makes an excellent producer of alfalfa.

It has been left to Colonel Z. S. Spaulding and his engineer, Mr. T. L. Knock, to go into this reclamation on a large scale and with the necessary capital for carrying it through. It has been found by him that by consistent draining and washing, the worst spot could be reduced to such a low percentage of alkali in three years that the alfalfa would grow and produce very heavily. Consequently he has divided this tract into forty acre tracts, putting a well on each

tract, and has started in to make the land a good producer of alfalfa. The water on this tract is about forty feet below the surface and pulls down to a pumping head of from fifty-five to seventy feet. Thus, to avoid the large expense of installation of putting down pits for horizontal centrifugal pumps, he adopted the deep well centrifugal pump for his work. The class of pumping installation he is using on this work is shown in Fig. 2. The entire ranch slopes to the southwest and is crossed by drainage sloughs. The engineers have taken advantage of these sloughs in their development and are using them now to assist in the drainage of their land. The land is first checked and leveled and lateral drains cut through in such a manner that the water can be readily removed from any section within a period of a few hours.

It will be noted that the salts named have a strong affinity for water and so their removal is greatly simplified. The method of removing them is as follows:—

The land is leveled and checked and, after drains

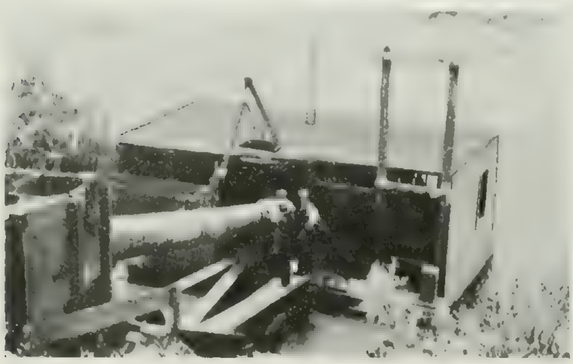

FIG. 7—FLOATING PUMPING PLANT OF MOULTON IRRIGATION LAND COMPANY IN SERVICE NEAR COLUSA

are put in, is sown to alfalfa. The reason for putting the alfalfa in is due to its fertilizing effect as well as to its assistance in holding the water on the land. In flooding the land, about one-third more water is applied than would ordinarily be used in alfalfa irrigation. As the water seeps into the ground, the last third is drawn off. This tends to carry away in solution a percentage of salts which are contained in the first six inches of soil. The amount removed by each irrigation will vary from one-half to seven percent of the total amount of salt in the soil; this being only over the first six inches in depth. As the water is removed from the land, the sun tends to draw the salt from greater depth than six inches to the surface of the ground. Thus the action is repeated on the regular irrigation period throughout the season. These irrigations vary from five to six per season and, with a late Fall, even to seven irrigations in one year.

It is found also that approximately twenty-five percent of an alfalfa crop can be grown the first year. In the second year, this crop will increase to about fifty percent of full crop, and in the third year from three-quarters to a full crop. Finally, in the fourth year, there is such a small percentage of salt in the land that it is then producing a full crop which will run from seven to ten tons per season. The fact that a certain production of alfalfa is obained each season tends to help pay the expense of the reclamation and also tends to fertilize the soil. When this project is completed, there will have been developed ready for the market, 10 580 acre of the best alfalfa land obtainable. Each forty acres will be complete with its own pumping plant for irrigation purposes and the ultimate purchaser will have fully developed land on which to begin work.

IRRIGATION ON RIVER BOTTOM LAND

For a great number of years the river bottom lands of the Sacramento and San Joaquin Valleys have been used in alfalfa raising and truck gardening. Due to the close water level at these points, ranging from six to twelve feet, very little irrigation was needed to produce a fairly good crop for the year. It is found, however, that it will pay to irrigate this land, and within the last year a great number of plants have been installed, some pumping from wells and others from the river. From five to six tons per year without irrigation, the alfalfa production increases to from ten to twelve tons with irrigation. Figuring alfalfa at an average of $10 per ton, it is evident that it pays to irrigate this land. On a certain class of this land, however, too much water is a great detriment, due to the fact that some of the land is of the peat variety and some of heavy clay, since that the water which is held in the soil tends to cause souring.

The Moulton Land and Irrigation Company have adopted a novel scheme for river pumping which is shown in Fig. 7. This installation consists of a twenty-inch pump belted to a 100 horse-power induction motor, the whole being mounted upon a barge. This enables them to have five different pumping points along the river. From the standpoint of the Moulton Company, this plant is advisable, due to the fact that they have only one plant to maintain and operate, which they are able to use for the several irrigating points, due to the diversified production of their project, and also because they can plant at different times, enabling them to use the water when it is available. This makes a more desirable load from the power company's standpoint, because they have one 100 horse-power motor operating over practically five months continuously, while if they had five individual plants, they would probably operate, to a greater or less extent, at the same time. The power cost to the consumer is reduced, for the reason that he gets a better power rate on his consumption by having one plant operating over a long period than he would by having the plants operating at the same time. It has also reduced the expense of operation, as one man can operate the barge plant, whereas it would be necessary to have five men to

operate the individual plants. Power is served at the different pumping points by the Pacific Gas & Electric Company, with their 11 000 volt distribution lines. The transformers are mounted directly on the boat, and consist of three 30 k.v.a., 11 000 volt transformers, reducing to 440 volts on the secondary.

RICE IRRIGATION

In the upper Sacramento Valley there is quite a large acreage of adobe land which heretofore produced very lightly. The reason for this is that the adobe, after drying out, becomes so cracked that alfalfa and grain produce very poorly. It has been found by experimenting, that rice will do well on this land.

The Moulton Irrigated Land Company have at the present time approximately one thousand acres of their ranch, five hundred acres of which is of the adobe character, planted in rice. It is found that, in rice culture, it requires from five to six acre-feet of water per season to bring the rice to full maturity. The ground is planted and then is irrigated enough to keep it moist for the first month to five weeks. As soon as the rice attains sufficient height, the ground is flooded and kept until the crop matures, which ranges from two and a half to three months. The amount of water required per day to keep the land flooded is, on all classes of land in this district, one-half acre-inch per day. The Moulton Company experimented with both the adobe land and the lighter soil in rice culture, and find that the lighter soil, although requiring slightly more water to flood, does not require any more water to keep the land flooded than the heavier or adobe soil. The lighter soil produces more rice.

FIG. 8—DIAGRAM SHOWING METHOD OF WATER MEASUREMENT FOR ESTIMATING PUMP AND WELL CAPACITY

There are two varieties of rice being raised by the Moulton Company, the Japanese and the Italian. The production of these two varieties of rice is practically the same, the advantage of the Japanese being that it matures earlier, enabling it to be harvested and removed from the land before the winter storms begin. The production on this land for the last year was approximately forty sacks per acre, the rice ranging from ninety-six to one hundred and five pounds per sack. As this culture is new in this section of the country, it is not known how many years the land will continue to produce rice in good quantities. It is estimated, however, that every fourth year the land should be given over to rest, and planted to some other class of product which would insure a better return during the other years.

The fact that the adobe land can be used in rice culture has increased its value from approximately \$12.50 per acre to the neighborhood of \$100 to \$125 per acre. The cost of power for irrigation of the rice land of the Moulton Irrigated Land Company is \$1 per acre-foot of water. They pump from the Sacramento river, using a thirty-inch centrifugal pump and 150 horse-power motor, the head being 22 [illegible] maximum. This does not include the cost of ditching nor the interest and depreciation on the cost of the plant, which would probably increase the cost of irrigation per acre-foot to approximately \$1.35. It appears, however, that the larger acreage which this customer is able to handle, reduces very materially the cost of irrigation, as proved by comparing the 1912 cost of their rice cultivation, when they had under cultivation two hundred acres, with that for 1913, when they had under cultivation nine hundred to one thousand acres.

There are at least two thousand acres of rice being grown in Butte county, for which the water is pumped from wells. The cost for water runs a little higher than it does on the river projects.

RESERVOIR SYSTEM

This type of installation consists of a reservoir, made by scraping a pit of sufficient area to hold the water pumped during a twelve to fourteen hour period. The pit bottom is usually covered with crude oil to prevent seepage. The size is governed by the size of pump installed and by the acreage under irrigation. The cost of the reservoir is not high and it can usually be placed on land that is low in value.

In sections where power is sold on a flat rate basis, that is, say \$30 for six monthts per horsepower, the installation of a small motor and a reservoir have reduced the cost of irrigation very materially. It also means that the farmer with a small motor can get twice the irrigation head during the day time, as he allows the pump to operate all night and have a full reservoir to start irrigation in the morning. It also proves an advantage in other districts where deep well pumping is made necessary and the amount of water obtainable at any time is small. This enables the operator to keep his plant running the full twenty-four hours and to irrigate during a period of ten to twelve hours, thus giving him twice the amount of water for irrigating during the irrigation period. This enables him to cover his land with less loss in water and time than he could possibly do with a direct irrigation system.

WATER MEASUREMENT

The following method of water measurement has proven very handy for estimating pump and well capacity. This method is based on the discharge pipe being full of water and the stream being discharged in the horizontal plane.

If the discharge pipe is full at BD, Fig. 8, then by laying a straight edge along ABC and measuring a distance BC so that CE is equal to one foot, then the distance BC equals one-fourth the velocity of the stream, or, when $CE = 1$ foot, $BC = \frac{1}{4} V$. Knowing V and the diameter of pipe BD, then quantity in gallons per minute $= 2.45 \times (BD)^2 \times V$. If the pipe is not full, this formula becomes simply an approximation.

The Engineering Evolution of Electrical Apparatus—III

THE ALTERNATING-CURRENT GENERATOR IN AMERICA (Cont.)

B. G. Lamme

During the past few years, some very interesting spider constructions for the rotating fields of large high speed alternators have been built to meet the severe speed requirements. Some of these have been made up of cast steel centers or spiders with cylindrical rims built up of overlapping laminated punchings, thoroughly bolted together and attached to the spider by dove tails. The outer periphery of the laminated ring carries dove-tail grooves for poles. In another construction, the entire spider consists of thick rolled iron plates, bolted together, and with dove-tail grooves on the outside for the poles. In still other constructions, the rim of the spider consists of a heavy steel ring in one or more sections to which the cast spider is bolted. Usually with this cast rim the poles are bolted to the spider. In some cases the rim forms an integral part of the spider itself, being cast with the spokes and hub. The type of construction adopted in each case is, to a large extent, dependent upon the stresses to be taken care of, so that no one type seems to fit all cases to best advantage.

THE PROBLEM OF VENTILATION

In the later rotating field alternators the problem of ventilation has received much consideration, especially in the case of machines operating at abnormal speeds. In very high speed machines of very large output the armature and field cores have a ratio of width to diameter which is relatively much greater than in ordinary machines, and this has necessitated abnormal conditions of ventilation. Something may be said here regarding the general problem of ventilation of alternators and its influence on the evolution. Back in 1891 or 1892, radial ventilating ducts or passages came into use commercially on certain direct-current machines. The results being quite satisfactory, it was natural that alternators should have the same method of ventilation. The use of such ducts was in reality one of the great steps forward in the evolution of dynamo-electric machinery, although but little recognition has been given to this fact in electrical literature. The use of radial ventilating ducts has continued to the present time with little change except in the construction of the spacers themselves, which have been many and varied in design and materials. With the change from the rotating armature to the rotating field construction of alternators this feature was retained in full. In some of the earlier Westinghouse rotating field machines the field structure also had numerous ventilating ducts, principally for the purpose of supplying ample air to the armature ducts. Also, about ten years ago, special ventilating end bells and vanes began to be used on rotating fields, in order to set up an extra air circulation through the armature end windings, etc., due largely to the fact that the slow-speed engine-type machines of that period did not have much natural blowing action. Following this, and partly as an outgrowth of turbo-generator enclosing, came the semi-enclosed alternators, mostly for high-speed water-wheel driven units, and this practice is not uncommon at present.

The proper ventilation of an alternator or, for that matter, of any dynamo-electric machine, is very much of a problem, for no two cases, in different sizes or types of machines, are quite alike. The problem lies first, in furnishing the proper quantity of air to carry away the heat developed, and in then distributing such air in proper proportion through the complex multiple paths in the machine. The proper distribution of the ventilating air is usually the most serious part of the problem. The present solutions of the problem are based largely upon past experience, and no really workable rules have yet been developed. In arriving at the present practice many disheartening experiences have been undergone by all designing engineers. The writer has known many cases where totally unexpected results, both good and bad, have been developed and, in some of these cases, no logical explanation was forthcoming, so that the results could not be taken advantage of, with any assurance, in future work. This has been one of the most discouraging features in the general problem of ventilation.

ARMATURE WINDINGS

Something might be added here on the subject of armature windings. There have been probably as many types of armature windings developed as there have been types of alternators. The windings for the earliest smooth body and the toothed armature constructions have already been described. In the early Westinghouse polyphase alternators, two-phase was used mostly, due principally to the fact that single-phase lighting circuits formed the principal load, and, with two-phase machines, there were only two circuits from a machine instead of three circuits with the three-phase winding. Moreover, many of these very early polyphase alternators were used in reality as straight single-phase machines, taking current off one phase only. For this purpose a closed coil armature winding, like that of a direct-current generator or rotary converter, with four taps for taking off the two phases, gave about the most economical type of winding, as far as armature copper losses were concerned. When such an armature is used for single phase it

can deliver seven-tenths as much output as a single-phase machine as it can give two-phase with the same total copper loss per coil. It was partly for this reason that many of the early Westinghouse polyphase

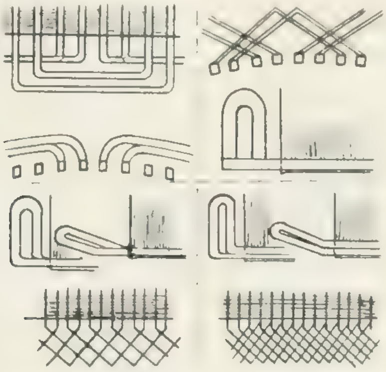

FIG. 11—VARIOUS TYPES OF EARLY STATIONARY ARMATURE WINDINGS

machines had a single closed coil winding. Another reason for such winding was that there were no definite phase groups and no high potential between phases. Furthermore, the arrangement of the end windings was such that the coils tended to interlock and support each other, thus assisting in resisting centrifugal forces. This winding was used mostly for two-phase machines, but was also used to a considerable extent on three-phase armatures.

With the advent of the rotating field type of machine, this closed coil type of armature winding was not used to any great extent, open-coil two-phase and star-connected three-phase taking its place. Delta-connected three-phase was used in very rare cases, as there was danger of circulating current with such windings.

In the construction of armature windings possibly more radical changes have taken place than in the types of windings. Many of the larger low speed rotating armature alternators had bar windings with separate end connectors, soldered or bolted on. Many of the earlier stationary type armatures had either built-up bar or strap windings, or concentric type windings in which each phase winding was arranged in a concentric group, and the groups of the different phases overlapped each other. Some of these were made with partially closed slots and others with open slots. The built-up bar or strap windings were frequently of the partially closed slot type, while the concentric windings were more usually of the open slot type. Gradually, however, both these types of windings were superseded by the "duplicate coil" type of winding, similar in appearance to the usual direct-current armature and induction motor primary windings. This later type of alternator winding was arranged in two layers of coils at the ends, in either one or two layers in the slots. The two-layer, two-coil per slot arrangement is now practically the standard. These types are illustrated in Fig. 11.

In the rotating field machines, partially closed slot construction was carried to comparatively high voltages. For instance, the 6 000 kilowatt, 75 r.p.m., 11 000 volt, three-phase generators built for the Manhattan Elevated Railway in 1900 had three bars side by side, in each slot, with soldered-on end connectors.

As the partially closed slot and the open slot constructions are radically different from each other, something should be said regarding the reasons which prompted the use of either type. As already indicated, the partially closed slot type came in with the larger rotating-armature low-voltage alternators in which bar windings could be used. This construction gave good mechanical support for the bars in the slots, thus avoiding the use of bands. Moreover, with the very narrow slot openings at the top of the slots, there was very little "bunching" of the magnetic flux at the armature tooth tips with the consequent low pole face losses, even with very small air-gaps, and high gap flux densities. The disadvantages of the partially closed slot is found largely in the type of windings required.

In these early machines, it was not found practicable, in general, to use completely formed and insulated coils with such slots, and therefore, either hand windings or built-up types of windings were used. While these were possible and practicable in a manufacturing establishment, yet such types of

FIG. 12—BAR AND END CONNECTOR TYPE OF WINDING WITH PARTIALLY CLOSED SLOTS

windings are usually difficult to repair by the ordinary operator inexperienced in the refinements of armature winding. When it comes to repairs, the usual machine-wound coil, which is completely insulated before being placed on the armature core, is very superior

but, in general, this type of winding requires an open slot construction. However, when the stationary armature construction came into general use, the advantages of the overhanging tooth tips in supporting the coils largely disappeared. There remained therefore the disadvantages of the flux bunching, against the advantage of coil construction, if open slots were used. However, the use of laminated poles, and the judicious proportioning of the air-gaps and flux densities, to a great extent eliminated the losses due to open slots. In consequence, the open slot construction and the duplicate type of armature coil, have apparently come to stay, in this country.

FIGS 13—DUPLICATE COIL TYPE OF WINDING, TWO COILS PER SLOT

Various attempts have been made to obtain the advantages of both the open and the partially closed slot arrangements. Probably all large manufacturers of alternators have tried some form of magnetic wedge, instead of the usual fibre or wood wedges which serve to retain the coils in the slots. Another arrangement is the equivalent of combining two or more open slots in one, with an over-hanging tooth tip, which covers the slot with the exception of the width of one coil. Two or more completely insulated coils are fed successively into the slot opening and arranged side by side. This does not give any narrower slot opening than with the open slot construction, but the number of openings is reduced to one-half, or one-third. This construction is used rather extensively in the rotors of large induction motors, but apparenty is but little used in generators.

Bracing of the end windings against short-circuit shocks has been a comparatively recent practice. The necessity for such bracing has been dependent to a considerable extent upon the output per pole, and the old time machine seldom had such a large output per pole that the short-circuit current-rushes were sufficient to cause dangerous distortions of the end windings. However, such bracing was used on the Niagara machines, previously described, and also on the Manhattan generators above referred to. These, however, were very rare instances. However, with the recent high-speed, high-output water-wheel generators, the outputs per pole have become such that some form of end bracing has become rather common.

Modern Westinghouse machines of this kind are braced to stand a dead short-circuit across the terminals without damage to the windings. Under this condition, these large machines may give a momentary current rush of from ten to twenty times the rated full-load current. However, the bracing required on the end windings of such machines is of relatively much less importance than on turbo-generators of corresponding capacity, due to the fact that, in the former class of machines, the end windings are relatively short compared with those of turbo-generators.

The above description brings us practically up to date, as far as the ordinary synchronous alternator is concerned. No description of the development of the turbo-alternator has yet been given. This forms a rather distinct development which should follow at this point presumably, but it is thought advisable to interpolate here some description of the problems of parallel operation, e.m.f. wave form, regulation, etc., which came into prominence and were practically taken care of previous to the advent of the turbo-generator on a large scale.

PARALLEL OPERATION OF ALTERNATORS

One of the great problems which developed in the operation of alternators was that of the parallel running of two or more units. At one time this was a very serious question, but in recent years, it is very seldom heard of. Considering the almost universal practice of paralleling alternators, which holds at the present time, one might be led to wonder why there ever was any trouble. Far back, in the days of the high-frequency surface-wound alternators, paralleling was attempted in many cases and, not infrequently,

FIG. 14—DETAIL VIEW OF THREE-PHASE CONCENTRIC WINDING

with considerable success. However, a failure in an attempt to parallel, in those days, usually meant the destruction of the apparatus. Those old time surface-wound alternators usually had very low self induction.

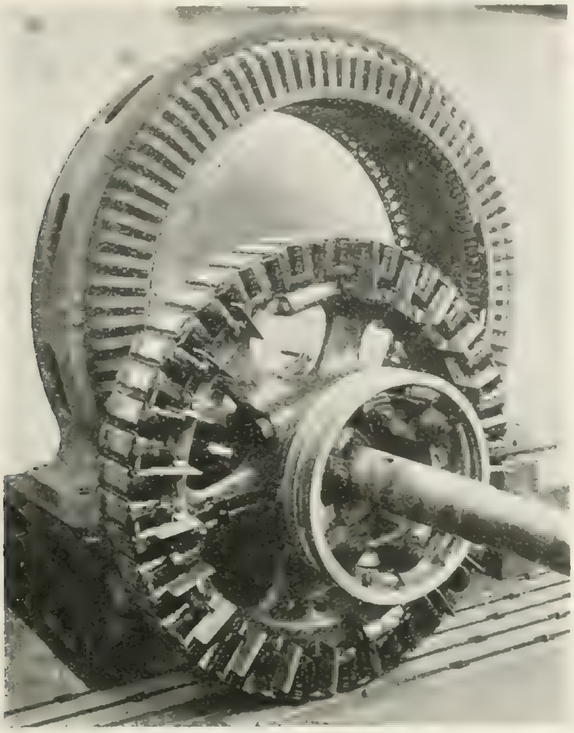

FIG. 15—75 K.V.A., THREE-PHASE, 60 CYCLE, 2 300 VOLT, 150 R.P.M. ROTATING FIELD ENGINE TYPE ALTERNATOR

so that, in case of sudden short-circuit, an enormous current could flow, sufficient usually to strip the armature winding from the core, by bursting the bands, or otherwise. A failure in an attempt to parallel two machines was practically equivalent to a short-circuit, and this usually meant destruction of the apparatus. However, if once paralleled successfully, the machines usually did not act badly. One favorable condition, not then appreciated, was that all these early machines were belt-driven. It may be said, however, that in those days parallel operation, while considered possible, was also considered more or less risky. In the period immediately following the surface-wound alternator, parallel operation was very much the exception, rather than the rule and, when engine-type alternators came into use, paralleling was considered for several years as very questionable. At this time the situation was as follows:—Belted alternators could be paralleled in many cases. Direct-coupled alternators, if flexibly driven, could be paralleled almost as well as belted machines, while direct-coupled or engine type generators, without flexible coupling or drive, could not be relied on to parallel without hunting. It thus became recognized that some flexibility between the generator and its prime mover was an important adjunct to parallel operation. This led to the consideration that the engine might be back of the difficulty in many instances, and it was then assumed that inequalities in the regular rotation resulting from insufficient flywheel or from hunting governors, tended to cause hunting in the generators. Investigation showed that such conditions did tend to produce hunting, but that the magnetic conditions in the machine itself would oftentimes maintain, or even accentuate, the hunting. Obviously, therefore, the trouble was both in the prime mover and in the generator. It was noted further that if the angular fluctuations in the driving power were relatively small, hunting usually would be very small, or would not be apparent at all. It was further recognized that, with belt or flexible drive, which tended to smooth out the speed fluctuations due to the prime mover, the hunting tendency tended to disappear. Attention was then turned toward improvement of the prime movers, especially in engine-type machines, in order to reduce fluctuations in angular velocity by means of heavy flywheels, and by means of dampers of some sort, such as dashpots, on the governing mechanism of the engine. Much improvement was accomplished in this way.

The Introduction of Dampers—During this period many attempts were made to lessen the tendency of the alternator to maintain hunting. Investigation showed that, during hunting, the magnetic flux in the field poles shifted back and forth across the pole faces in time with the hunting, while such action did not occur when there was no hunting. This at once led to the theory that a low resistance winding on the pole face , or imbedded in the poles, would prevent or oppose this flux shift, and thus assist in overcoming hunting. However, about this time, rotary converters were coming into use, and it was found that, in such machines, hunting was usually more severe than in alternators, so that, in this country, the first true application of damping windings or devices to stop hunting were applied on rotary converters. It was also noted at this time that solid pole generators and rotary converters did not hunt to the same extent as did lami-

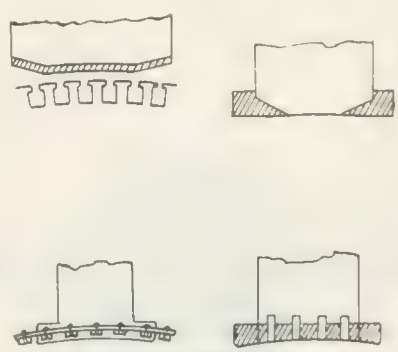

FIG. 16—VARIOUS FORMS OF DAMPERS

nated pole machines, and it was correctly assumed that the solid pole faces gave an effect similar to that of low resistance damping windings. However, as it was desirable to use laminated pole tips, copper dampers on the poles gradually came into use. Some of these early dampers were very crude in form and type compared with present constructions. However, imperfections in the construction of the dampers were balanced to some extent by the large section of copper used

and consequent low resistance. The earliest form of damper used in this country consisted of copper rings surrounding the poles and copper tips overhanging the beveled pole edges. This was the form most commonly used on converters. On alternators, in some cases, the damper consisted simply of a low resistance ring around each pole. In still other cases the damper con-

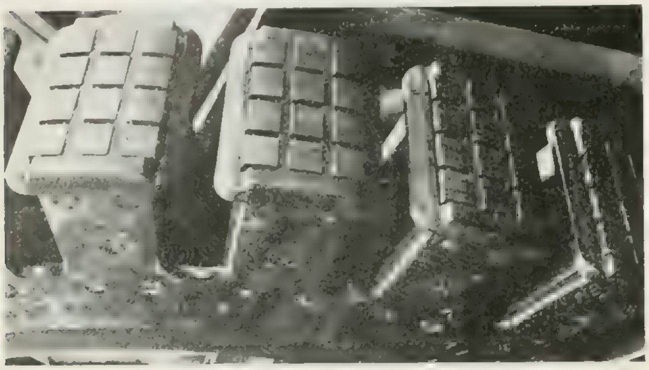

FIG. 17—GRID DAMPERS ON FIELD POLES

sisted of a heavy copper plate covering the pole face. This latter construction was only possible in machines with large air-gaps and very narrow or partially closed armature slots. These crude forms of dampers were gradually superseded by the so-called "grid" damper which consisted of a copper grid surrounding the pole and with ribs which lay in slots in the pole face. These various types of dampers are shown in Fig. 16. In very few cases were these old types of dampers so interconnected as to form a complete cage winding around the field.

Many tests were made at various times to determine the effect of interconnecting the grids on the different poles to form one complete cage. As a rule, there was no appreciable gain, and it was then assumed that such interconnection had no material advantages. However, it later developed that the reason why interconnection of the dampers did not improve the damping action very materially, was due largely to the very great amount of copper in those parts of the grid dampers lying between the poles.

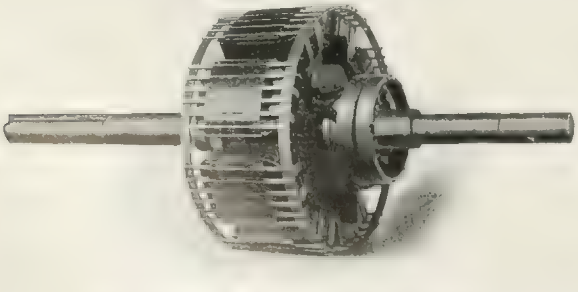

FIG. 18—CAGE WINDING TYPE OF DAMPER

The grid damper was very effective, but was expensive in material, and was not easily applied on poles with overhanging pole tips. This type of damper was gradually superseded by one smilar to the usual cage winding on the secondaries of induction motors, and this is the type which is in most general use at the present time. This construction has practically the same effectiveness as the old grid type, but is much more economical in material and, being placed in partially closed slots, it does not as greatly affect the iron losses in the machine, as was liable to be the case with the open slots, generally used with the grid damper.

With the gradual introduction of dampers and improvements in angular rotation of the prime movers, hunting troubles in alternators practically disappeared, and parallel operation presented no difficulties, except under very abnormal conditions. Apparently these dampers or "amortisseurs," as they are sometimes called, were first proposed by the French engineer, Maurice LeBlanc, about 1891. However, they were "rediscovered" in this country by engineers who were not familiar with the above engineer's work.

VOLTAGE WAVE FORM

The e.m.f. wave form of alternating-current generators has been a matter of much discussion since the early days of alternator design. The old surface-wound machines gave a very close approximation to a perfect sine shape, due to the arrangement of the winding and to the very large air-gap. The first toothed armatures, with their very small air-gaps, gave e.m.f. waves which departed very widely from a

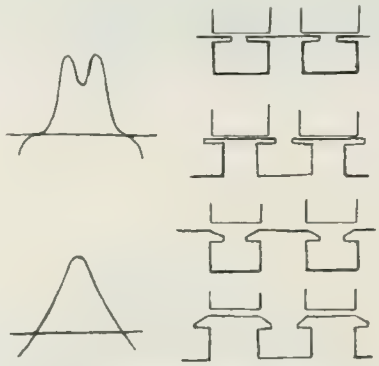

FIG. 19—VOLTAGE WAVE FORMS

Of early toothed armature machines and of later toothed armatures with larger air gaps and beveled poles.

true sine. In fact, this had about the worst wave form of any of the alternators which have been put out by the Westinghouse Company. Its shape was somewhat like that shown in Fig. 19, as would now be expected when the configuration of the armature tooth tips is taken into account. The later toothed armatures with large air-gaps and beveled tooth tips gave much better wave shapes.

With the advent of the true polyphase windings and the slotted armatures with several slots per phase per pole, fairly close approximation to sine shaped e.m.f. waves became common. In the first Niagara Falls 5 000 horse-power, two-phase alternators, the voltage wave was slightly flattened on the top due to the fact that the pole face width was somewhat greater than the width of each phase group in the armature. When very high voltages came into general use, and especially in machines with small pole pitch, the number of armature slots per phase per pole was reduced to a minimum in order to lessen the total insulation space. In extreme cases, but one slot per

phase was used, giving but two slots per pole for two-phase and three slots per pole for three-phase. Such windings required special shaping of the field pole tips in order to approximate even roughly a smooth wave form of the sine shape. Later practice, however, has tended toward the equivalent of at least two slots per phase per pole, in order to obtain better results. Sometimes the desired result is obtained by the use of one extra idle or "hunting" tooth per phase.

In the early days of parallel operation of engine type alternators which, as described before, represented the most difficult conditions, great stress was laid upon the question of wave form in some of the discussions of parallel operation, and particularly, in the operation of rotary converters without hunting. Gradually, however, this question disappeared and it became recognized that all the cases of hunting encountered could be explained in some other way than by the e.m.f. wave forms, and it is now generally accepted that about the only effect on parallel operation due to wave form lies in possible circulating currents of higher frequency than the fundamental.

At the present time, a very close approximation to the sine shaped wave is considered preferable for general purposes, especially in transformation and transmission work. There have been some instances of telephone disturbances due to wave form but, as a rule, some local peculiarities of the distribution circuits have been involved in this trouble, for, in other cases, similar or even worse shaped waves have given absolutely no telephone disturbances.

REGULATION AND COMPOUNDING

Something should be said on the subject of regulation of alternators, for this is a very important characteristic, and has had considerable influence on types and designs. The old surface-wound alternators had extremely good regulating characteristics due to their low armature self-induction and low armature reaction consequent upon their large air-gaps. The writer does not know what value the current rose to, on steady short-circuit, compared with the normal rated current, but it was probably four or five times full load. The current rush on short-circuit was probably five times as great as the steady value. It is not to be wondered at that such armatures not infrequently wrecked themselves in case of a dead short-circuit. In the later toothed armature types, the armature self-induction and reaction on the field were very much larger, proportionately, than in the surface-wound machines. This, however, spoiled the regulation and some method of compounding was used, as already described. This compounding was common practice until larger capacity machines, especially the engine type, came into use. Even some of these latter were compounded by commutating the armature current (either directly or from a series transformer) and compounding the exciter field by means of the commutated current. A few of the smaller size alternators were both self-excited and compounded by commutating derived alternating-current circuits from the armature. This, however, was found to be very delicate, as the excitation and compounding were greatly affected by changes in the power-factor of the load, and by changes in speed.

One early attempt was made to compound single-phase alternators to correct for power-factor. In this case the commutated armature current was sent through the series or compound winding of the exciter. The brushes on the alternating-current commutator were so set that at 100 percent power-factor they were commutating about the middle of each voltage wave. In consequence, the current delivered to the brushes was not a true direct current but consisted of a double number of half waves, half of which were inverted, and the direct-current component of this commutated current was small and had but little compounding effect. However, with change in power-factor of the load, the phase of the current shifted, so that at some reduced power-factor, commutation occurred at the zero point of the current waves and the resultant current was all effective for magnetizing the exciter field. The total commutated voltage was very low and the commutator bars were shunted by a resistance so that there was no bad sparking, even when commutating at the middle of the current wave. This method did actually compound fairly well for change in power-factor, but the field for such method proved to be very limited, for compounding of alternators fell into disuse shortly after this.

The usual method of compounding on the early alternators was simple series current compounding, just as in direct-current apparatus. Where the commutated current was supplied directly to the field compound winding, voltages of about 30 to 60 volts were most common at rated full load. With much higher than 60 volts, there was a liability of short-circuiting the compounding by arcing between bars on the commutator. There was also a liability of arcing or flashing when the phase of the current shifted due to change in power-factor.

When polyphase rotating armatures came into use, similar methods of compounding were resorted to. However, the secondary current was a resultant of the two, or three primary currents, for each of the primary phases was carried around the compensating transformer (or spokes of the armature) and the secondary winding carried a current in phase with the resultant of the primary ampere-turns. In the case of three-phase windings, the direction of one lead was reversed around the compensating transformer. Some curious conditions arose from the phase relations of the secondary current when parallel operation was practiced. It was necessary, when parallelling the main winding, to parallel also the compound winding. As the compounding current from each machine pulsated from zero to maximum value in each alternation, it was necessary to so parallel the terminals that all the commutated currents had zero value at the

same instant, otherwise, the brushes on one commutator would, at times, short-circuit the current from the other commutator.

With the advent of larger belted machines, and of engine-type machines in particular, the compounding of polyphase machines was more or less unsatisfactory and was practically abandoned. To compensate for the lack of compounding, better inherent regulations were aimed at in the designs. This meant, primarily, machines which would give comparatively large currents on steady short-circuit, three to four times full load being rather common, and even six times full load being attained in some machines. The momentary current rush at the instant of short-circuit must have been excessive on some of these machines, due to their very low armature self-induction. However, due to the relatively small ampere-turns per pole, no very destructive distortions were found in practice. This characteristic of the short-circuit currents was carried into the rotating field construction, and even into the early turbo-generator work.

This practice of giving the alternators good inherent regulation was expensive in a number of ways, as it usually meant higher iron losses and less output than was possible otherwise, with a given size machine, or a given amount of material. Even at this early date, it was recognized that some form of automatic field current regulator which would maintain the terminal voltage constant, regardless of the inherent regulation, would be a very useful piece of apparatus. Some form of regulation which would take care of change in power-factor, as well as load, was the aim of many designers. Among the different schemes brought out, the Rice method of compounding, brought out by the General Electric Company, is of interest. This was used principally with rotating field alternators. In this scheme, the exciter was usually placed on the same shaft as the alternator field, and, in such case, had the same number of poles as the alternator. The leads from the alternator armature were carried through the exciter winding in such a way that a lagging current, carried by the alternator, tended to strengthen the field of the exciter by shifting the armature reaction with respect to the exciter field poles. In this way a compounding action on the exciter was obtained which was practically in proportion to the demands of the alternator field with varying power-factor. In the case of engine-type machines of comparatively low speed, the exciter was geared to the alternator shaft, so that it ran at a considerably higher speed and the number of poles in the exciter was correspondingly reduced.

This method of compounding was effective, but the whole combination was apparently unduly complicated and expensive. Furthermore, it did not give the desired compensation under all conditions of operation, as it would not correct for changes in speed.

A later method of compensation for power-factor was devised by Alexanderson, and was used on a limited number of General Electric machines. In this scheme a derived current from the alternator itself was commutated in such a manner that compensation, proportional to the power-factor, was obtained. This was a purely self-excited alternator scheme and, like all self-exciting schemes in such apparatus, it was sensitive to speed changes, probably to a much greater extent than the Rice arrangement above described. A fundamental defect in all self-exciting compensated alternator schemes lies in the fact that stability of excitation is dependent upon having considerable saturaton in the alternator magnetic current and, coincidently, if there is such saturation, the compound current has no direct relation to the load or power-factor. Thus such machines are either sensitive to speed changes, or their compounding is only approximate.

Following these scheme came the use of automatic regulators of which the Tirrill is best known. This regulator acts directly on the exciter field by short-circuiting a resistance in series with the field winding, the range of exciter voltage being controlled by the length of time the rheostat is short-circuited. Instead of cutting the resistance out in steps, which tends to give sluggish action in the fields, the Tirrill regulator cuts the whole resistance out each time, and the length of time is varied. This results in quick action. As the regulator tends to hold constant voltage at the alternator terminals, or on the line, change in power-factor or in speed does not modify the action. This type of regulator has proven very effective, especially in the case of alternators subjected to sudden and violent changes in load, power-factor and speed.

With the advent of larger alternator units, in proportion to the changes in load, the inherent regulation has been made relatively poorer, primarily because better machines otherwise are thus obtained. The short-circuit currents are reduced, and relatively lower iron losses, and lower temperatures or, higher outputs with a given temperature, are obtained. This has been carried further in turbo-generator design than in any other class of alternators, due partly to fundamental limitations in design. However, this poorer inherent regulation has proven to be of no practical importance, where suitable automatic regulators have been used with the machines.

One fallacy which was frequently found in the past, and which still persists to some extent, is that alternators should have equal inherent regulation to parallel properly. This is based partly on the feeling that the field currents of the alternators should vary over equal range when carrying their proper proportion of load, together with the knowledge that the variations in field current are dependent, to some extent, upon the inherent regulation. However, the fact that the shape of the saturation curve, in a given alternator, may have much more influence on the excitation, especially at high saturations, is usually overlooked.

(To be continued)

The Growth of the Central Station Power Industry

S. A. FLETCHER

THE PRESENT day tendency in manufacturing is well indicated in the growth of the central station industry which is fast coming to the position where it will supply the majority of the power used in manufacturing. Manufacturers generally are realizing that a single large power company, which supplies power for many different organizations, can sell that power more cheaply than it can be manufactured in smaller isolated plants. Consequently the central stations have grown enormously in the last few years, and today are producing nearly one-fifth of all the power used in manufacturing. The rate of increase is growing greater year by year, so that it will not be long before more than half of all the power used in manufacturing will be supplied by power companies.

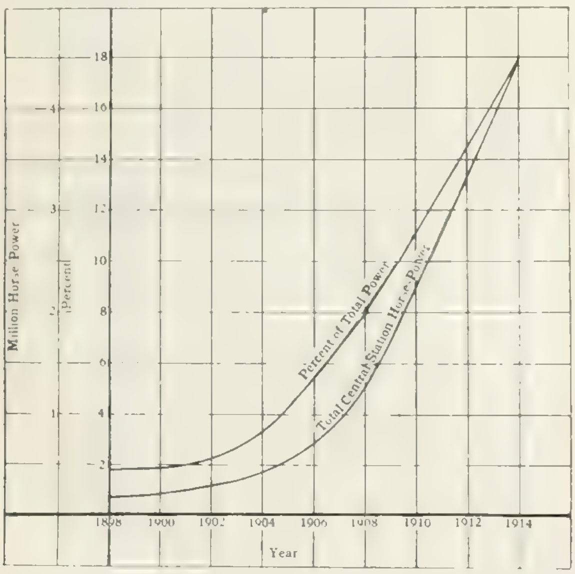

FIG. 1—CURVES SHOWING RATE OF INCREASE OF CENTRAL STATION POWER, AND ITS PRECENTAGE OF THE TOTAL AMOUNT OF POWER GENERATED IN THE UNITED STATES

In order that the sale of any article may continue steadily year by year, or increase in amount, it is necessary that there be two satisfied sides to the bargain. Therefore it is apparent that there must be a tremendous army of satisfied users of central station power all over the country, or there could not have been this phenomenal increase in the use of central station power.

The central stations generally, have been aggressively soliciting power for only a short period of time. However, the nation wide campaign for motor business which has been carried on, has caused the business men of the country to realize the advantages of using a power which is really reliable as well as convenient and economical. This favorable attitude has progressed so far that it is safe to predict that during the present year, not only will the total amonut of electrical horse-power which will be sold be equal to the total increase required by all manufacturing industries throughout the country, but will actually be nearly 10 percent greater, and practically one-half of this will be central station power, or in other words, more than one-half of all of the power which will be required in the coming year for additions to old plants and for new plants, will be supplied from central stations.

These facts are shown by an examination of Fig. 1. This covers only the power used in manufacturing, without including the power used in mining, and in central stations or electrical railway stations. The curves have been extended in a conservative manner to show the probable amount of electrical horse-power that will be used in the year 1914, and the percentage of the total horse-power used in manufacturing which this will be at the end of 1914. It is very evident that in the last four years, from the end of 1909 to the end of 1913, there has been an extremely rapid increase in the percentage of power supplied from central stations, compared with the total power used in manufacturing, having increased from 9.4 to 17 percent in the four years, or an average increase of 1.9 percent per year. It is further to be noted that the rate of increase is more rapid than the average, and that in the year 1914 this may be expected to increase to 19 percent. As shown also in Fig. 1, this means an increase in total horse-power supplied from central stations, of 640 000 horse-power. A part of this power will be in new plants that will be built during the year; a part in old plants which are being extended; and a part in old plants which are being changed over from other forms of power, and will include some isolated plants which have already been electrified but which will find in 1914 that central station power is more economical and satisfactory than isolated plant power.

Six hundred and forty thousand horse-power is a large amount to be added to the central station circuits in one year. It must not be thought that this business will come inevitably to the central station, because such is not the case. If every central station manager gets his own full share of the business throughout the country, at the end of 1914 it will prove that as much power as this has been added. This will be true only on the following condition:—It is perfectly possible for each station to receive its share, if every person in the central station organiza-

tion does systematically the work assigned to him. It devolves therefore, upon the manager to determine how much is his full share of the business in his territory, and then to set this up as the minimum amount of power which he will endeavor to add during the year. He should further separate this total into portions for each solicitor, and then stimulate each one of his solicitors to try to exceed this value. If this be done intelligently it will serve as a very satisfactory stimulant.

A good plan is for each manager to make a definite survey of the power that is available in his own territory by taking a census of all of the places where power can be used. This census will require that the solicitors make a quick canvass of every power user and prepare a separate report on each one, showing the class of business which the prospect is doing, the amount of power which he will require, the type of power which he is now using, the condition of his equipment, whether it is good or bad, and any other notes which will help in determining which are the most active prospects and which will be the most benefited by the central station power. These can then be classified as to the industries and assigned to the solicitors by industries, rather than by territories. Thus, after the manager has determined how many prospects there are in his territory, and how many in each line of manufacturing, it becomes possible for him to charge each salesman with a certain definite number of industries, each industry having a known number of prospects with a known total horse-power possible. From this it becomes possible to make assignments which shall be suited to each man's ability and to the class of work which has been assigned to him.

With such a complete analysis of the prospects, the manager has before him a map of the places where power should be used, and can satisfactorily lay out circuits if it is deemed advisable, with a view to the amount of power which will probably be used from that circuit within a reasonable time. The manager himself also has a very definite and concrete idea as to how much work is assigned to each power solicitor, and therefore how much business he ought to be able to turn in. When a solicitor is assigned to a certain section of territory, he has no adequate notion of how much business is actually to be had in that territory. It is only human for a power solicitor to strike a gait, as it were, which is not as high as it is possible for him to reach, and therefore he sets for himself a certain amount of business as being a good day's work, and this figure is inevitably too low. However, if the manager has a complete analysis of the territory, he has the means to show each power solicitor exactly where his shortcomings are and how he may raise his personal load-factor.

By classifying the prospects according to industries, each solicitor can select the most promising industry in his apportionment and work upon it consistently and systematically for a certain length of time, and then later take another industry and devote his energies to that, and so on. In this way he will be able to make a systematic study of the requirements of each industry. By this study, a solicitor will learn how best to apply the motors to the machines, so that the most efficient operation may result. He will study the requirements of the individual machines and the manner in which the operators handle them, and may often be able to suggest improvements in the location of the machines, which will be possible with motor drive, or in the method of routing the material due to the possibilities of relocating the machine, which will effect material economies in the manufacture. In this way the solicitor becomes an expert on each industry and secures for his customers the maximum amount of work for a minimum amount of power used. On the other hand, the power solicitor who works by territories will handle several different types of industries in a day, will not become familiar with the manufacturing processes in any industry, and therefore will have greater difficulty in securing installations which will represent the most efficient possible method of drive. Hence, he will not be liable to secure for his customer the maximum advantages of central station power, and therefore the customers will not be as well satisfied as those of the solicitor who studies each industry systematically. It is inevitable that the solicitor who works by industries will become a specialist on each industry as he takes it up, and that the man who works geographically will become a generalist who merely gets the surface facts without digging into the problem to determine its true merits.

Therefore, each central station manager should endeavor to secure an increase in business, commensurate with the total increase for the entire country, which would be two percent of the total new horse-power installed in his territory, if all of the power in the country were upon the lines of the central stations. This is not the case, however, and on the assumption that half of the power used in manufacturing is not at the present time in central station territory, the probable increase becomes four percent of all of the power used in manufacturing in his territory. This does not mean four percent of the power which is not electrified, but four percent of the total power, including that which has already been electrified.

Every manager can therefore take at least six percent as the least increase for which he will work for the year 1914.

Reversing Motor Planer Equipment

W. B. Nicklas

A MOST interesting motor application to machine tools, both from an engineering and production viewpoint, is the direct-current reversing motor equipment as applied to planers and other machine tools having a reciprocating motion. It has been but a few years since the good features of this method of drive were first appreciated. At the present time the demand for these equipments has increased to such an extent that the electrical builders are able to manufacture and market them on a commercial basis.

A most important feature of this reversing motor drive over the old system of complicated belts, pulleys and shafts is the speed economy, often as high as 44 percent, that can be obtained in the operation of the planer. This is made possible by the use of the adjustable speed, commutating-pole, direct-current motor in conjunction with the magnetic type of automatic control.

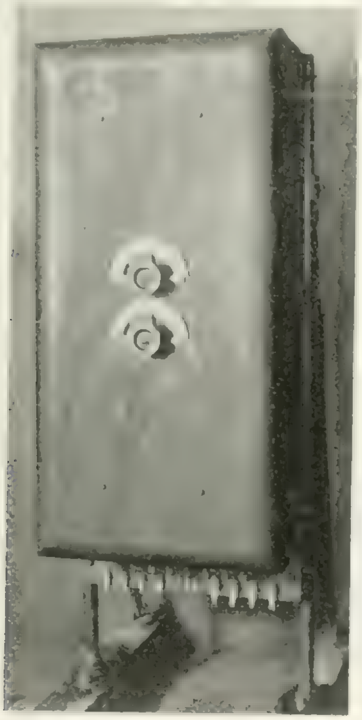

FIG. 1—MAGNETIC TYPE CONTROL FOR REVERSING PLANER MOTOR

The upper rheostat handle regulates the speed during the cutting stroke, and the lower one, the return speed.

DETAILS OF EQUIPMENT

The magnetic type controller is shown in Fig. 1, and a view with the dust-proof cover open is shown in detail in Fig. 2. This apparatus was developed with a view of successfully meeting the abnormal conditions caused by the constant starting, stopping and reversing. Two handles mounted on the front of the cover control the two field rheostats which in turn independently control the cutting and return speeds of the motor. Thirteen separate speeds in either direction of rotation are available, which gives a range for the cutting up to 50 feet per minute while the return of the platen of the planer can vary from 50 to 100 feet per minute. The speed depends upon the weight, dimensions and method of holding the work on the planer.

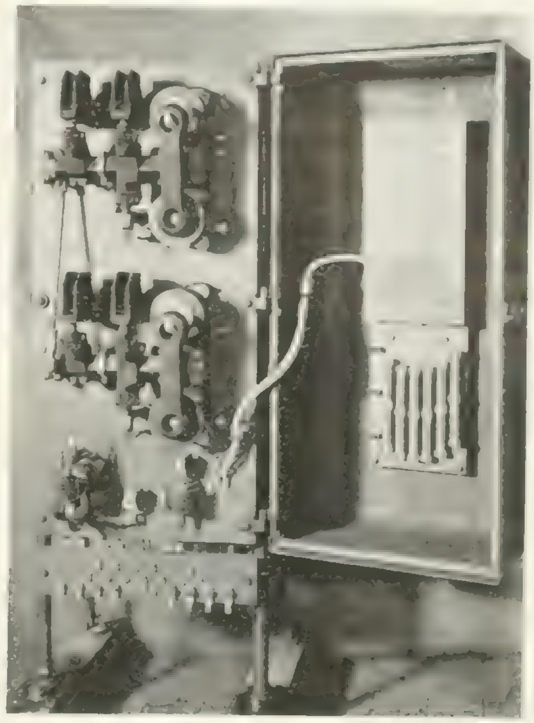

FIG. 2—MAGNETIC TYPE REVERSING MOTOR PLANER CONTROLLER WITH COVER OPEN

In order to meet all of the most severe planer requirements of starting, stopping and reversing under heavy loads at various speeds, it was deemed advisable to design a very rugged compound-wound motor, such as shown in Fig. 3. The frame is of solid steel, the extra large bearings are oil and dust-proof and the

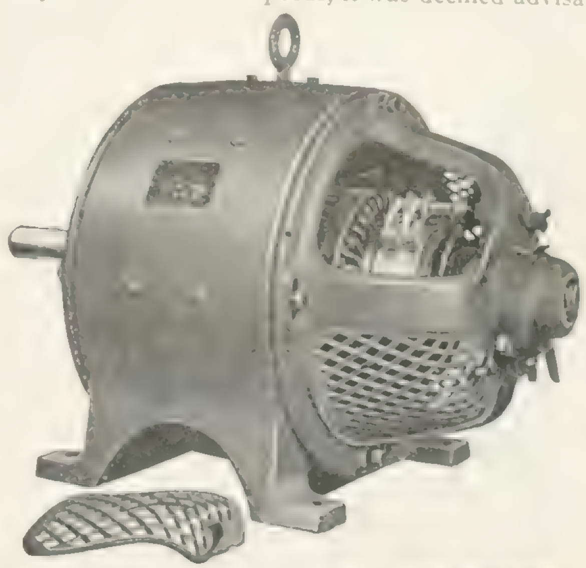

FIG. 3—35 HORSEPOWER REVERSING PLANER MOTOR

shaft is made of axle steel of sufficiently large dimensions to insure rigidity. The armature, Fig. 4, is small in diameter as compared with a standard motor of similar horse power rating, so that the flywheel effect is low. The commutating poles insure sparkless commutation over the entire speed range of the motor. It can readily be seen that a motor so liberally and carefully designed will withstand the severe strains to which it is continually subjected.

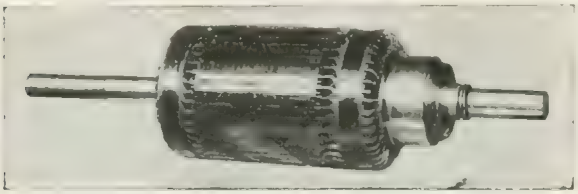

FIG. 4—35 HORSE-POWER REVERSING PLANER MOTOR ARMATURE

The motor is started by means of a pendant switch, after which the reversing and speed adjustment are handled automatically. The operator is thus able to give his entire attention to the cutting surfaces, and the adjustment of his tools.

FIG. 5—MASTER SWITCH

The master switch, Fig. 5, is mounted on the bed and is tripped by dogs located on each end of the platen. It is entirely enclosed to protect it from chips; a spring throws the drum to the *forward* or *reverse* position with a quick snap action. The pendant switch, Fig. 6, is suspended over the platen by a flexible cable from the controller, and may be carried about by the operator, enabling him to start, stop and reverse the platen from any point within the radius of the cable length. It is, however, entirely independent of the master switch, as it is used principally to start the motor as well as to obtain an "inching" speed while the operator is setting up his work.

FIG. 6 — PENDANT CONTROL SWITCH

The controller is equipped with protective devices so that the platen may be quickly stopped in case of failure of voltage or in the event of an open circuit in the shunt field of the motor. This fully protects the planer, as it prevents the platen from running off the bed and thus causing damage.

The difference between the old and the more modern types of equipment is illustrated by Fig. 7, which shows a 72 by 96 inch by 24 foot open side planer, driven through shifting belts, and Fig. 8, which shows a 60 by 60 inch by 16 foot open side modern planer equipped with a direct-connected reversing motor and automatic control. This planer weighs 90 000 pounds, and is designed to handle heavy rough work, such as is found in a steel foundry. It is equipped with two heads on the cross rail and one side head, while, depending on the nature of the work, it develops a cutting speed from 14 to 28 feet per minute, and a return speed from 28 to 56 feet per minute.

The two illustrations, Figs. 7 and 8, clearly show the difference in the auxiliary apparatus required with each method of drive. With the non-reversing motor, an elaborate system of belts, pulleys, shafts and shaft-hangers is necessary. This increases the first cost of the installation, while the upkeep of the belts is very expensive. Additional overhead room is required, which may interfere with the free operation of the overhead cranes. With the reversing motor, these details are entirely eliminated, as the motor is direct connected to the platen of the planer through proper gears.

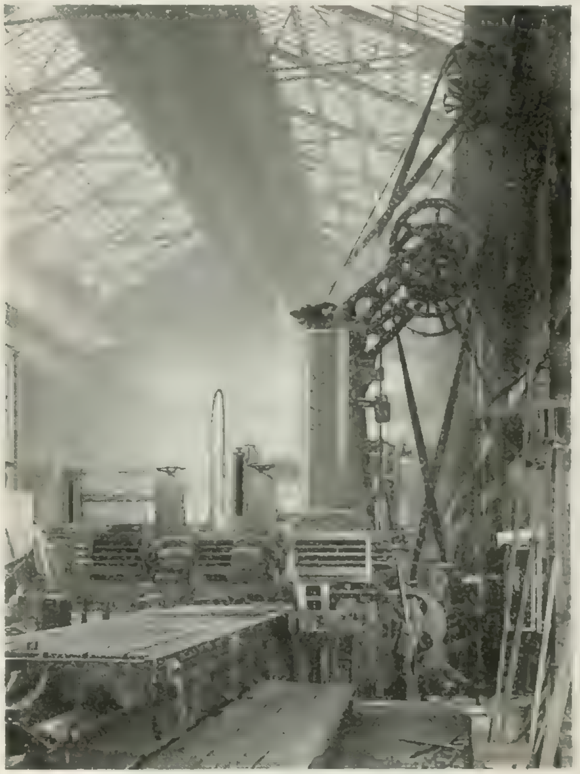

FIG. 7—OPEN SIDE PLANER, BELT DRIVEN BY A NON-REVERSING MOTOR

Note the numerous belts, shafts and pulleys.

PLAN OF OPERATION

The operator starts the motor by means of the pendant switch, which automatically, through the magnetic switches on the control panel, brings the motor to the desired speed, determined by the setting of the field rheostat. The platen travels in a forward

direction, during which period the cutting is performed, until the end of the stroke is reached. At this point the master switch is tripped by the dog on the platen, thus almost instantly bringing the motor to rest electrically and, through a second set of magnetic switches, accelerates it in the return direction. At the opposite end of the stroke the master switch is tripped by the other dog, the motor again comes to rest and the cycle of operation continues.

The length of the stroke, when once fixed, is found to be much more nearly constant than is the case when belt drive is used, as belt slippage is entirely eliminated by gearing the motor directly to the platen.

ECONOMY PRODUCED BY THE REVERSING MOTOR

On belt-driven planers the productiveness of the tool is limited by:—

1—Belt slippage.
2—Flywheel inertia of the pulley.
3—One cutting speed available in most cases.
4—One return speed available in most cases.
5—Time lost due to breaking and repairs of belt, counter-shaft and to main line shaft.

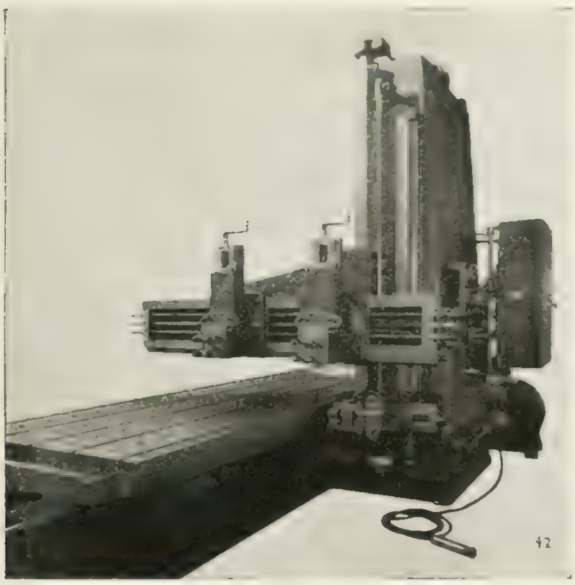

FIG. 8—OPEN SIDE PLANER, WITH ADJUSTABLE SPEED REVERSING MOTOR AND AUTOMATIC CONTROL EQUIPMENT

Note the absence of belts, shafts and pulleys.

The productiveness of the tool is increased when the reversing outfit is employed because:—

1—There is no belt slippage.
2—The flywheel inertia of the pulley is eliminated.
3—The cutting speed is adjustable; the most economical speed can be used at all times for different cuts and materials.
4—The return speed can be adjusted to suit the mounting and the inertia of the work on the planer bed.
5—There are no belts and counter-shafts to be repaired and no time lost thereby.
6—Time is saved in setting up the work, due to the possibility of moving the planer a fraction of an inch, at will, with the master switch or with the pendant switch.

COST OF MAINTENANCE

Where belts are used, maintenance charges will include:—

1—Cost of labor and materials for replacement and repairs of belts.
2—Cost of labor and materials for pulley and counter-shaft repairs.
3—Value of time lost in making repairs.
4—Cost of general maintenance, oiling pulleys, tightening belts, etc.
5—Maintenance of motor and control.

Where the reversing motor is used, items *1, 2, 3* and *4* are eliminated. Item *5* will be the same for

TABLE I—PLANER OPERATING EXPENSES

Dollars per machine-hour

1 Size of Planer	2 Int. and Dep. on Cost of Tool	3 Cost of Power	4 General Operating Expense	5 Supervision and Clerical Work	6 Total Machine Hour Rates
Inches					
36	$0.04	$0.02	$0.49	$0.25	$0.80
48	0.09	0.02	0.59	0.30	1.00
56	0.12	0.04	0.69	0.35	1.20
60	0.18	0.04	0.70	0.35	1.27
72	0.19	0.04	1.05	[illegible]	1.81
120	0.28	0.04	1.26	0.64	2.22
120 Heavy	0.82	0.06	2.04	1.13	4.05
130	0.22	0.06	2.66	1.35	4.29
168	0.60	0.06	2.79	1.42	4.87
168 Heavy	0.97	0.06	3.89	2.14	7.06

either method of drive. The cost of the first four items varies considerably for different shops, depending largely on the working conditions and no specific figure can be given.

The operating expenses of all machine tools can be expressed as machine hour rates, and depend on:—

1—The size of planer.
2—Interest and depreciation on cost of tool.
3—Cost of power.
4—General operating charges, based on general repairs and replacements, storage, hauling, tool room charges, interest and depreciation on cost of building and auxiliary apparatus, such as cranes, lights and other miscellaneous operating expenses.
5—Salaries for supervision and clerical work.

Table I contains those values for planers in a large shop, doing a variety of work, based on 2 800 hours per year operation with a charge for power at two cents per kilowatt-hour.

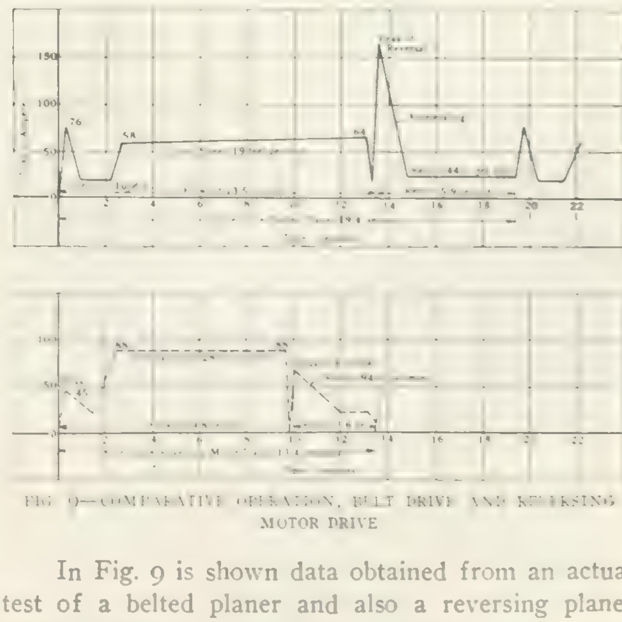

FIG. 9—COMPARATIVE OPERATION, BELT DRIVE AND REVERSING MOTOR DRIVE

In Fig. 9 is shown data obtained from an actual test of a belted planer and also a reversing planer motor equipment. The depth of cut, the feed and the length of stroke was the same in each case. The result of this exhaustive test shows an increase of pro-

duction, where the reversing motor outfit was used, of approximately 33 percent, with a corresponding decrease in the amount of power consumed. In practical results, the reversing motor equipment has increased the output of planers 33 percent, thus reducing by 33 percent the labor charge and the machine overhead charge entering into the cost of each piece of work.

While the cost of power is a small portion of the cost of operation, it is worth considering and shows a saving in favor of the reversing planer motor. With belt drive, the motors and belts run much of the time, while the planer is doing no work, that is between jobs and while setting up the work. On account of the friction in the pulleys, belts and shafts, measurements show that such planers require almost 25 percent more power per unit of output than when driven by reversing motors. Integrating meter readings on motor driven applications show the following records for a period of two weeks:—

	Total Hours Operated	Kilowatt-Hours Total	Kilowatts per Hour
Non-reversing motor, belt drive..	103.5	490	4.75
Reversing motor drive...........	[illegible]	380	3.92

Fig. 10 shows an oscillograph record covering a cycle of operations of a planer equipped with a reversing motor. The instrument was connected to indicate the line current during acceleration and cutting, and to show the armature current generated during dynamic braking. The fact that this peak does not occur on the line is one advantage of dynamic braking. An additional advantage lies in the fact that when the planer is reversed less current is required than is the case with the belt driven planer. In the latter case, power must be supplied from the line to

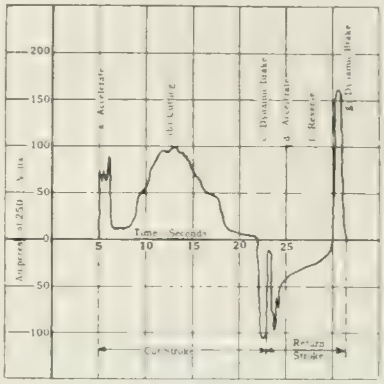

FIG. 10—OSCILLOGRAPH RECORD OF REVERSING PLANER MOTOR

stop the moving parts and accelerate them, whereas with the reversing drive, power to accelerate the moving parts only is supplied from the line.

This general type of adjustable speed reversing equipment also furnishes an economical method of drive for slotters, millers and other machine tools having a reciprocating motion.

Placer Mining With Bucket Dredges

W. M. Hoen

IN THE PAST, placer mining has furnished a large portion of the world's gold supply, but to-day the richest places are exhausted, so that operations are chiefly on a large scale working low grade deposits. In the early days of the mining industry in California, placer mining was done on a large scale by hydraulic sluicing. This method is now practically obsolete, due somewhat to legislation, but chiefly because large amounts of water and favorable locations are necessary.

The lower grade deposits require a method of working whereby large amounts of gravel can be handled at a low unit cost. The result of these requirements is seen in the development of the ladder dredge, and such dredges in their present sizes as well as their successful operation would not be possible, except for the utilization of electric power.

NATURE OF GROUND AND MECHANICAL REQUIREMENTS

Placer deposits are of alluvial origin and may either be on the surface or covered with overlying rock. Of these, the more important are on the surface, overlying bed rock in depths of varying thickness, and to take care of this range of depth, dredges are in operation which dig as far as 70 feet below the water line. The deposit may consist of gravel which is either loose or so firmly cemented as to resemble conglomerate. The highest gold values are found close to bed rock so that the digging ladder and buckets of a dredge must be capable of working under the most severe conditions. The wear on the buckets, line and tumblers is so severe that they must be made of manganese steel. The buckets vary in size from 1.5 to 16.5 cubic feet, and the power required for a bucket of a given size will vary with the nature of the ground.

DESCRIPTION OF DREDGE

Gold dredges which are floated in a small pond may differ in their various details. The buckets may be open, that is, with a bucket on every other link of the chain, or close-connected, that is with a bucket on every link of the chain; it may be held in position by head lines or by spuds, depending upon the nature of the ground; the disposition of the waste may be by a conveyor belt and stacker or by a long trough or sluice. The latter type however has a very limited field of operation.

The main features of a gold dredge are:—

Digging ladder and bucket chain, trommel or screen, hoist for raising ladder, hoist for lateral motion of dredge, hoist for moving stacker and spuds (sometimes combined mechanically with lateral motion hoist), stacker and conveyor belt and pumps.

The endless bucket chain passes over a large tumbler at the top end of the ladder, which is driven

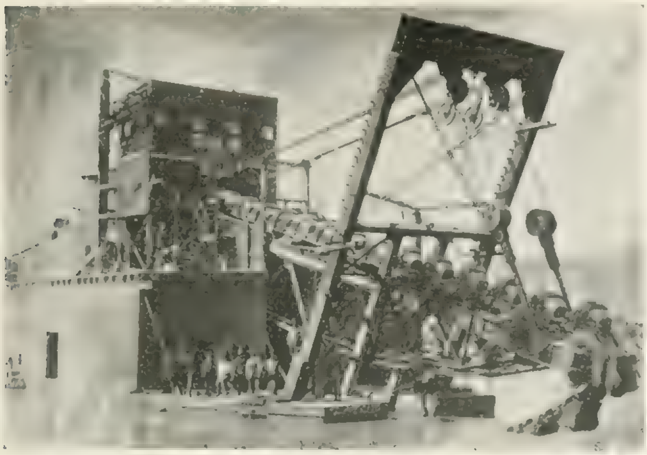

FIG. 1—ONE OF THE LARGEST GOLD-DREDGES IN THE WORLD
Each bucket has a capacity of 16.5 cubic feet, and weighs 4 890 pounds.

through several massive gear reductions. The ladder and gear mechanism is mounted on two heavy timbers or steel beams running the length of the dredge. On the majority of the dredges the last reduction between the gear shaft and motor is made by a belt, while the other characteristic type uses a gear reduction to the motor.

CHARACTERISTICS OF DIGGING LOAD AND TYPE OF MOTOR

When starting a new cut the ground is generally light, the buckets fill easily and are operated at the maximum speed. The nature of the ground may vary greatly throughout a digging cycle. As depth or heavier ground is reached, more power is required and the buckets will not fill so rapidly so that it is necessary to operate at a reduced speed. The service is very severe, heavy shocks being caused by the buckets slipping over large boulders. At times, these overloads are so severe that there is danger of parting the bucket chains if no relief measures were provided. This sometimes happens and causes a serious delay to production. It is inadvisable to have the motor circuit breaker open, as a stoppage causes considerable delay, and several delays during the day would seriously affect the yardage output.

To reduce the maximum stresses caused by these severe shocks, a friction clutch is placed in the gear reduction mechanism and adjusted to slip at the maximum loads. This class of service requires a motor of the wound rotor type capable of giving maximum horsepower output at reduced speeds.

CONTROL APPARATUS

The control apparatus for the digging motor is generally placed in the pilot house, which is at a considerable distance from the motor. When operating at the maximum speed, this extra resistance due to the rotor leads is beneficial when these heavy momentary overloads occur, as the friction clutch does not always slip as intended and the momentary slowing down of the motor will take place without any opening of the motor circuit breaker. These momentary peaks are very frequent, and if the bucket chain were not slowed down momentarily a shut-down would result.

On a large dredge the resistance grids required for the control will take up considerable space and require a large amount of wiring. On one of the new dredges described later, a liquid rheostat, such as is used in hoisting service, is installed in the pilot house. This has greatly simplified the control problem and is very successful. When the motor is operating at low speeds, considerable energy must be absorbed by the rheostat, and as the pond water is unfit for circulation in cooling coils, the electrolyte is circulated by means of a small pump through cooling coils suspended in the pond, at the side of the dredge.

NATURE OF OTHER MOTOR LOADS

The operations of raising the digging ladder, the lateral motion of the dredge, moving the stacker and raising the spuds require motors of ordinary heavy torque characteristics as built for intermittent service. The last three operations are sometimes taken care of by one motor using a multiple drum hoist. Motors of the squirrel cage type are preferable for driving the screen, if it is belt-driven and the same will apply to the stacker belt. Starting currents will be heavy, but they will be small compared to the power taken by the digging motor. The pumps are

FIG. 2—DETAIL VIEW OF BUCKETS OF DREDGE SHOWN IN FIG. 1, WHEN DREDGE IS OPERATING AT NEARLY ITS MAXIMUM DEPTH

in several units of the centrifugal type delivering large volumes of water under low heads for the gold tables and at moderate head for the screen jets.

SWITCHBOARD

The switchboard is installed in the pilot house and should be as light and compact as possible and well braced to withstand the heavy vibrations. The

digging motor and all operations relative to the movements of the dredge are controlled from the pilot house. One man has entire control of the digging operations and is held responsible for the yardage produced on his shift.

THE DREDGING PROCESS

The digging buckets elevate the gravel into a screen, generally of the revolving type, and copious streams of water separate the pay dirt from the coarse gravel. In the stacker dredge, the gravel is elevated and deposited on the spoil bank. The material containing the value is diluted with water and passes over the tables where the values are caught in riffles, these riffles being filled with mercury. In a sluice dredge, the tables are in the sluice; however, this type of dredge requires much larger amounts of water than the other. At suitable intervals, generally once a week, a clean-up is made which consists in removing the amalgam from the riffles. The gold is then recovered from the amalgam by distilling off the mercury. The dredges are operated continuously,

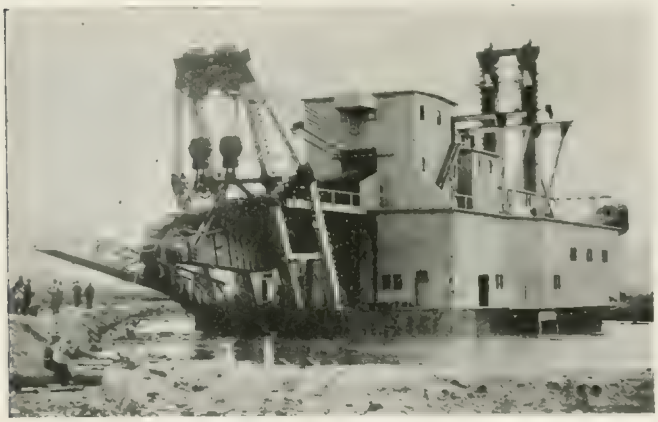

FIG. 3—ONE OF THE ELECTRICALLY-OPERATED GOLD DREDGES IN THE ALDER GULCH DISTRICT

unless climate conditions or shortage of water interfere.

A LARGE INSTALLATION

The following is a brief description of one of the largest dredging installations in the world. The largest dredge used has a hull 150 by 58 by 13 feet, and draws 9 feet of water. It is one of four operating in the Alder Gulch district in Montana. The digging ladder is 116 feet long, center to center, and carries a chain of 80 close-connected buckets. The buckets are of manganese steel, weighing 4 890 lbs. each, and the connecting pins are of nickel steel. This bucket chain is operated by a 550 horse-power motor, the speed varying from 22 buckets per minute for light ground down to 17 for heavy. The ground resembles conglomerate, so that the power requirements are heavy and the wear on the buckets is very severe. The ladder can be lowered so that digging can be carried on 53 feet below the water line. Its movement is controlled by a 200 horse-power hoist motor. This dredge digs an average of 300 000 cubic yards per month.

The elevated gravel is dumped into a revolving screen 58 feet in diameter, 50 feet long and weighing 19 200 lbs. It is belt driven by a 100 horse-power squirrel cage motor. Several large jets of water wash the gravel as it passes down the screen, and the finer particles are washed through, passing over the gold tables, then into the pond. The course gravel is elevated by the stacker belt and deposited on the bank. This stacker is 130 feet long and contains a 48 inch conveyor belt driven by a 50 horse-power motor. Water to the amount of 1 250 gallons per minute is supplied by several pumps in units of 100 horse-power. Smaller pumps are used for handling the bilge water and for general uses.

Two box steel spuds weighing approximately 44 tons each hold the dredge in place and are used for stepping ahead. The lateral swing of the dredge is controlled by anchor lines and a 50 horse-power hoist motor. In operation the dredge is moved back and forth by means of the side lines about a spud as a pivot, and the digging ladder is lowered a given amount at the reverse of each swing. Several small motors are installed for operating an air compressor and small shop tools.

Although climatic conditions in this district are very severe at times, operation is continuous throughout the year, a locomotive type of boiler being used for heating. Power is supplied from a sub-station at 2 200 volts, except to one dredge, which is supplied at 6 600 volts. The lower voltage is used direct, transformers being installed on the other dredge. Power consumption on each dredge of this type will vary from 0.6 to 2.5 kw-hr. per cubic yard of material handled, depending on the nature of the ground.

Of the other three dredges in this district, besides the large one above described, two are of the stacker and spud type with close-connected buckets of 7.5 cubic feet capacity. These dredges will dig 35 feet below the water line and handle approximately 100 000 cubic feet per month. The third dredge is of the sluice type with close-connected buckets of 9.5 cubic feet capacity each. This dredge requires 15 500 gallons of water per minute.

A machine shop completely equipped with heavy machine tools is maintained for repair work on each of the four dredges and a gasoline tractor, with a trailer having a capacity of 25 tons, takes care of transportation problems.

Dredges of the larger size, having buckets of 15 cubic feet or more, are to-day working in ground in which the values run as low as eight cents per cubic yard. Dredges of these large sizes will sometimes have an operating cost as low as two cents per cubic yard.

Typical Electric Power Plant Costs

M. C. McNeil

THE COST of producing power is less today than ever before, notwithstanding the fact that the price of fuel and labor, two of the most important factors affecting power cost, have increased. The explanation of this rather remarkable truth may be summed up in one word—efficiency. This efficiency has been effected by the general progress in plant construction, operation and management, and by the centralization of power in large stations, which are inherently efficient owing to their size, and by the betterment of the load factor that always obtains as a result of the more diversified load prevailing in large plants. The load-factor referred to here is the ratio of the average load during any period, as 24 hours, to the average maximum load for one hour during that period. The average maximum load may be more or less than the rated capacity of the plant, though in good plant design it is always more than the normal capacity of the plant.

Logically, the central station scheme should be carried to the practical limit of never having two stations where one will serve. Other things being equal or not affecting the selection, one station should be used when the economies produced are greater than the extra transmission losses occurring.

Nowadays when a power plant is spoken of, it is understood, unless otherwise specified, that the prime movers in the station are turbine units, the condition considered here. The cost of construction, or, as more commonly called, the cost of installation, complete from real estate up to and including all auxiliary apparatus, for a given size of plant, is fairly constant throughout the country; as all the power and auxiliary equipment is standard and consequently the cost is practically constant. Local conditions, though, with reference to competition in the sale of the apparatus, price of real estate and quality of material used in power house construction, do affect the installation cost to some extent, and, in some instances, may cause quite an appreciable variation from the general or average case. However, the size of the plant does effect the cost very materially. With power plants, as with anything else that might be mentioned along manufacturing and industrial lines, the unit cost tends to vary inversely as the size of plant, increasing quite rapidly for small plants and decreasing less rapidly for large plants.

The installation cost of a plant affects the cost of power produced, in that the fixed charges (sometimes called overhead) are a certain percentage of the installation cost usually around 10.5 percent for turbine plants. This is made up of interest 5 percent, taxes and insurance 2 percent and amortization fund 3.5 percent. The amortization fund covers obsolescence and depreciation, and is so proportioned that a certain percentage, say 3.5 percent, if set aside annually and allowed to accumulate at, say, four percent compound interest, will always be of sufficient amount to make any changes or replacement that may be demanded in the ordinary occurrence of events. The fixed charges, being a definite percentage of the initial plant cost, will vary accordingly as the initial cost varies.

The total cost of power, consisting of the operating cost and fixed charges, is a fluctuating quantity, depending upon two principal conditions; namely, size of plant and load-factor. Most of this variation is due to the operating expense, which constitutes about 80 percent of the total power cost, and is made up of the following items mentioned in the order of their relative importance; fuel, labor, repairs and maintenance, oil, waste and supplies.

Fuel (coal being considered owing to its almost universal use) is by far the largest factor in operating cost, rarely being less than 50 percent and sometimes as high as 80 percent of the total. The widest fluctuation occurs in the fuel item also, for in addition to the general factors of plant size and load-factor, there is the variation in the price of fuel in different parts of the country, as well as in the same locality, depending upon the quality and quantity used. The larger the plant the better the fuel economy, as large turbines are inherently more efficient than small ones, a fact that is also true for the boilers and all of the auxiliary apparatus. As the load-factor falls off, the fuel cost increases due to increased steam consumption per kilowatt-hour produced, since turbines operating at fractional loads are less efficient; and there is also a proportional increase in auxiliary power as the auxiliaries use nearly as much power at fractional as at full plant load. The general plant losses and inefficiencies are all proportionally greater, the smaller the plant and the lesser the load-factor, still further increasing the fuel item per unit of power produced.

The labor cost follows the same general trend as the fuel cost, although it is not so fluctuating, tending to be a fairly constant factor for any given plant due to the fact that the labor around a power plant is of the skilled or semi-skilled class and, therefore, the wages and salaries are practically uniform the country over. For a small plant the labor efficiency is very low, as a certain force is necessary to operate the plant whether each individual is working at his normal rate all the time or not. This so-called labor efficiency increases with the size of the plant until 100 percent is reached, above which point the labor cost tends to increase directly as the size of the plant, although the true proportion is never reached, as, for instance, the labor for a 50 000 kilowatt plant will not

be twice that necessary for a 25 000 kilowatt plant. The load-factor does not affect the labor as much as it does the fuel item, as practically the same labor for a plant having a 75 percent load-factor will be required by one having a 50 percent load-factor if the maximum load for the two plants is the same. However, this may not be the case if the light load of the 50 percent load-factor plant is of sufficient duration to make it practical to reduce the labor force during such times. Large plants warrant the installation of labor saving devices, such as the mechanical handling of coal and ash; such additions being an economic improvement when the extra fuel cost for operating and the additional fixed charges are less than the cost of labor dispensed with.

The items oil, waste and supplies, and repairs and maintenance are rather indeterminate quantities, although experience has shown that they bear an approximate relation to labor and fixed charges; oil, waste and supplies being around 20 percent of the labor cost, and repairs and maintenance about 15 percent of the fixed charges.

TABLE I—COST OF INSTALLATION

Items	Size of Plants—Kilowatts					
	500	1000	2000	3000	4000	5000
Building, real estate and excavating	16.75	11.50	13.25	12.00	11.00	10.00
Turbines and generators	32.60	25.75	21.15	17.30	15.80	15.00
Condensers	10.60	6.75	4.50	3.90	3.50	3.00
Boilers, stokers, superheaters and stacks	32.65	28.50	25.50	23.60	21.50	20.00
Bunkers and conveyors	5.50	5.00	4.50	4.00	3.50	3.25
Boiler feed and service pumps	1.25	1.25	1.00	0.75	0.50	0.50
Feed water heaters	2.00	1.75	1.50	1.25	1.00	0.80
Switchboard and wiring	3.50	3.25	3.25	3.00	2.75	2.75
Exciters	4.00	3.00	2.00	1.50	1.00	0.75
Foundation (machinery)	1.25	1.25	1.00	1.00	0.75	0.75
Piping and conduits	5.75	5.75	6.00	6.00	6.25	6.25
Crane	1.65	1.75	1.50	1.25	1.00	0.75
Superintending, engineering, etc	6.50	5.00	4.25	3.75	3.25	3.00
Total	123.60	103.50	89.40	79.30	71.80	66.80

To substantiate the statements and assertions that have been made it seems pertinent to give some actual figures on installation and power costs. This data is given for central stations varying in size from 500 to 5 000 kilowatts. A greater variation obtains within this range than for larger plants, and the points brought out will be more clearly appreciated.

Each of the plants are considered in Table I as normal rated at the size given in the table. The 500 kilowatt plant, for instance, has three 200 kilowatt normal rated units, a very generous arrangement, making it possible to operate the plant nicely with two turbines running, the third unit only being used during the peak. However, if one unit is shut down for repairs the peak load can be handled by the remaining two machines, though at reduced economy, as 600 kilowatts is considered as the maximum load for this plant. Ample capacity is provided, such as a spare boiler, extra boiler feed and service pumps, and other extra apparatus consistent with good power-plant design.

A point in Table I that may be open to criticism, is that the labor saving apparatus is not warranted for the smaller plants. Considering the 500 kilowatt plant, the cost of labor dispensed with does not offset the cost of the extra fuel required for operating the labor saving machinery and the additional fixed charges for the same, the total power cost probably being increased about three percent. The 1 000 kilowatt plant is about the dividing line, above which size the favor would lie with the labor saving machinery.

All the items in Table II are self explanatory except that of fuel, which was calculated for $3.00 coal. For simplicity, the steam operating conditions of all the plants were considered the same, being 175 pounds steam pressure, 100 degrees superheat and 28 inches vacuum. These conditions may be rather high for the smaller units. However, there would not be much difference in the total power cost if the steam pressure was lowered and superheat omitted, as the saving in fuel due to the more economic operating conditions just about balances the extra fixed charges.

In central station service the ideal condition of 100 percent load-factor is never reached and seldom approached, the condition of 75 percent load-factor

TABLE II—COST OF POWER GENERATION

Size of Plant Kilowatts	Cost in Cents per Kilowatt-Hour						
	Fuel	Labor	Oil Waste and Supplies	Repairs and Maintenance	Operating Cost	Fixed charges	Total
	100 Percent Load-Factor						
500	0.449	0.132	0.026	0.025	0.632	0.148	0.780
1000	0.364	0.094	0.019	0.021	0.498	0.124	0.622
2000	0.328	0.073	0.015	0.018	0.434	0.107	0.541
3000	0.304	0.065	0.013	0.016	0.398	0.095	0.493
4000	0.289	0.058	0.011	0.014	0.372	0.086	0.458
5000	0.271	0.053	0.010	0.013	0.347	0.080	0.428
	75 Percent Load-Factor						
500	0.548	0.166	0.033	0.031	0.778	0.197	0.973
1000	0.428	0.116	0.023	0.026	0.593	0.165	0.758
2000	0.389	0.088	0.019	0.021	0.517	0.143	0.660
3000	0.352	0.079	0.016	0.019	0.466	0.127	0.593
4000	0.327	0.072	0.014	0.017	0.430	0.115	0.545
5000	0.308	0.065	0.013	0.016	0.402	0.107	9.509
	50 Percent Load-Factor						
500	0.741	0.236	0.047	9.042	1.066	0.296	1.362
1000	0.558	[illegible]	0.033	0.035	0.792	0.248	1.040
2000	0.494	0.118	0.024	0.030	0.666	0.214	0.880
3000	0.438	0.106	0.021	0.027	0.592	0.190	0.782
4000	0.402	[illegible]	0.019	0.024	0.542	0.172	0.714
5000	0.380	0.088	0.017	0.022	[illegible]	0.160	0.667

being considered very good and only attained in some instances. However, the data given for these various load-factors considered shows very nicely the point of varying power cost and indicates what cost it is possible to attain if the plant load-factor can be improved. Referring to Table II, the total cost of power, as well as the cost of each separate item, for the 5 000 kilowatt plant is seen to be about 50 percent of what it is for the 500 kilowatt plant. For a 50 000 kilowatt plant this same proportion would not hold good, as each separate item, and consequently the total, decreases at a much slower rate above 5 000 than above 500 kilowatts. Observing the difference in successive pairs of items in Table I, it will be noted that they become smaller as the plant size increases, the tendency being for the item to become constant.

Therefore, the total unit power cost for the 50 000 kilowatt plant would be about 75 percent of that of the 5 000 kilowatt plant or about 0.32, 0.38 and 0.50 cents per kilowatt hour for load-factors of 100, 75 and 50 percent respectively.

Owing to the fact that the turbine is not the only prime mover used in central stations it may be of interest to note briefly some comparative figures on installation and power costs of other types of stations, such as the gas engine, the reciprocating steam engine and the combination of reciprocating steam engine and low pressure turbine. The comparison will only be a fair one if like conditions are considered in each case as,. for instance, the same fuel. Using coal as the fuel, the gas engine station is at once limited to a producer gas lay out, which however, conforms very well with the other plants in that the producers in the gas engine plant occupy the same relative position as the boilers do in the steam plants. For simplicity, only one size of plant, (1 000 kilowatts normal capacity), will be considered, the data and conditions for each plant being the same

TABLE III—COST OF INSTALLATION

Plant	Cost per kilowatt
Turbine	$103.50
Reciprocating steam engine	132.00
Combination reciprocating engine and turbine	127.00
Gas engine	162.50

as cited in the turbine plant comparisons. The installation costs of the 1 000 kilowatt plants are given in Table III. This table may be criticised on the ground that the costs of the other plants as compared with the turbine are too high, but when the plant conditions adhered to are recalled, the data as given will be appreciated as being correct. The turbine plant as designed was capable of handling the maximum plant load with one unit shut down, and similarly the other plants must be capable of handling the maximum load with one of their units shut down. To do this, the gas engine plant will have to have a larger normal capacity than the reciprocating steam engine plant, which in turn will have to have a larger normal capacity than the turbine plant. This is true from the fact that the overload capacity of a turbine is about 50 percent in excess of its normal rating, while the overload capacities of reciprocating steam engines and gas engines are about 20 and 10 percent respectively, so that the actual normal plant capacity is the greatest for the gas-engine plant and least for the turbine plant, though the installation cost per kilowatt is considered for the rating of 1 000 kilowatts in each and every case. For other sized plants the same proportional figures will be approximately correct, and so, referring to Table I and preceeding paragraphs, the installation cost of any sized plant can be found.

The cost of producing power for the different plants is given in Table IV. For plants of other sizes than 1 000 kilowatt, as here considered, the same proportion of values will be approximately correct. The turbine economy however, is proportionally better for larger units than is either the gas engine or reciprocating steam engine, though the reverse is true to some extent for smaller units. The fixed charges are different for the various plants, being 11.5 percent for the gas engine, 11 percent for the reciprocating steam engine and 10.5 percent, (as before), for the turbine. This difference is in the item of amortization fund, which covers obsolescence and depreciation, being 4.5 percent for the gas engine, 4 percent for the reciprocating engine and 3.5 percent for the turbine. This may seem to be discriminating in favor of the turbine but experience has shown that the above percentages are quite fair. The other items making up total operating cost can readily be approximated for any capacity plant and so the total power cost may be determined.

TABLE IV—COST OF POWER IN CENTS PER KILOWATT HOUR

1 000 Kilowatt Plants	Fuel	Labor	Oil Waste and Supplies	Repairs and Maintenance	Operating Cost	Fixed Charges	Total
100 Percent Load Factor							
Turbine	[illegible]	0.094	0.019	[illegible]	0.498	0.124	[illegible]
Reciprocating steam engine	[illegible]	[illegible]	0.023	[illegible]	0.542	0.166	[illegible]
Combination recip. and turbine	[illegible]	0.110	[illegible]	0.025	0.500	0.158	0.658
Gas engine	0.260	0.165	0.033	0.335	0.483	[illegible]	[illegible]
75 Percent Load Factor							
Turbine	[illegible]	0.116	0.025	[illegible]	[illegible]	[illegible]	0.758
Reciprocating steam engine	0.461	0.128	0.025	0.030	[illegible]	0.222	[illegible]
Combination recip. and turbine	0.404	0.134	0.030	0.032	0.600	0.211	0.811
Gas engine	0.334	0.195	0.039	[illegible]	0.612	[illegible]	[illegible]
50 Percent Load Factor							
Turbine	[illegible]	[illegible]	[illegible]	[illegible]	0.792	0.248	[illegible]
Reciprocating steam engine	0.602	0.182	0.039	0.040	[illegible]	0.332	1.195
Combination recip. and turbine	0.527	0.189	[illegible]	0.043	[illegible]	0.316	1.117
Gas engine	0.482	0.252	0.052	[illegible]	[illegible]	[illegible]	1.267

Making Power Investigations

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BRIEFLY STATED the cost of power, which is one of the important features in the operation plant, depends on three things:—

1—Investment charges.
2—Operating expenses.
3—Uses of steam.

The first two items can generally be obtained from the book records but the third can only be obtained by careful tests.

As a general rule it is safe to say that any plant which does not use steam for any purpose except for power can make a saving by purchasing power. But when large quantities of live and exhaust steam are required for the manufacturing processes, such as in paper mills or tanneries, the decision can only be made after very careful tests and the exact amount of steam required is known.

To obtain this information accurately the services of an expert are usually required. An experienced engineer can readily see what tests are necessary in order that the investigation be made in the shortest possible time and still obtain the required information.

In making these investigations almost as much depends upon the engineer as upon the information he gathers. He must be skilled in electrical and mechanical subjects and must also be a natural mechanic. In addition to the above requirements, he must be resourceful and tactful, as opposition will often be encountered in making this kind of an investigation. The men in the power plant and shop will regard the stranger with suspicion and even the broad minded executive will sometimes balk at having inefficiencies exposed which may reflect upon his management. Consequently the engineer must have a pleasing personality and be able to win the confidence and support of the men upon whom he must call for information and help. He must be prepared to doff his white collar, put on overalls and become one of the workmen.

The first thing to be done in starting an investigation into the power costs of any manufacturing establishment is to make a careful survey of the plant and plan just what tests are necessary and when they can be made without interfering with the manufacturing process. The engineer goes over the power plant and other buildings carefully, making notes of the uses of steam and power. If he has had much experience in this line of work, the process of manufacture will probably be familiar to him. If not he must learn the general facts and conditions of manufacture as affecting the use of steam and mechanical power. After he has obtained a general idea of the layout of the plant and the conditions to be met he makes arrangements to start his tests.

Complete information must be obtained regarding the amount of steam generated, the various uses of steam, both live and exhaust, the amount of mechanical power used, the operating expenses and the investment charges, and the output of the plant, as it is very desirable to make the report in terms of cost of power used per unit of product.

As a general rule the steam tests require the most time, so the engineer will first decide what pipes must be drilled in order to connect the steam meters and when the tests will be made. This work must usually be done at night or during a shut down period. The engineer must endeavor at all times to cause as little confusion and interruption to service as possible. The holes are usually all drilled and tapped at one time and the proper test plugs inserted. This will cause only one shut-down as the plugs are equipped with valves and the steam meter can then be moved from one place to another. Arrangements are next made for the installment of the proper electrical instruments, if the plant generates its own electricity. The usual way is to insert shunts or meter transformers in the bus-bars behind the switchboard. Then the meters may be installed and removed whenever it is desired.

The engineer must be supplied with indicating, integrating and graphic electrical instruments, graphic steam meters, steam engine indicators, graphic speed meters, tachometers and stop watches. Of course it should be known in advance whether the plant to be tested has alternating or direct-current generating equipment. The most important instruments used are the graphic ones. An exact knowledge of the existing conditions in the plant is essential if the investigation is to have any value. This knowledge may be obtained by keeping continuous records, by personal readings or by the use of graphic instruments. Graphic instruments have the advantage over the personal observations because they eliminate the personal equation and expense. They also furnish a continuous record for as long as desired. Valuable information may be obtained as to the best methods of economizing in operating expenses by continuous records as obtained with a graphic meter. They will show any inefficiencies in the handling of the apparatus.

The operation of some of the instruments used is so well understood that no description of them is necessary* but several of those now used are comparatively new and a brief description of their operation is given below.

THE STEAM FLOW METER

The graphic steam flow meter and the method of connecting it to the steam lines are shown in Fig. 1. The steam pipe is drilled and tapped the

*See article in the Journal for May, 1911, p. 416; July, 1910, p.536; Nov., 1909, p. 674; May, 1906, p. 297.

nozzle plug, shown in detail in Fig. 2, is inserted and the meter proper is then connected to this plug by flexible metallic tubing. If steam is flowing in the pipe, the resultant pressure is made up of two parts; one is the pressure due to the static head of the steam; the other is the pressure due to the velocity and weight of the steam. The leading set of holes in the steam plug, Fig. 2, is turned in the direction

FIG. 1—A GRAPHIC STEAM FLOW METER INSTALLED
Showing method of connecting to steam line.

opposite the flow of steam and the trailing set is turned in the direction of the flow of steam. Then the pressure due to the static head of the steam alone will be transmitted to the flexible tubing by the trailing set, while that due to the static pressure plus the velocity head of steam will be transmitted through the leading set of holes, so that as long as steam is flowing there will be a difference in the two pressures.

The meter proper consists of two mercury cups joined at the bottom and hung on knife edges which

FIG. 2—NOZZLE USED IN CONNECTION WITH A STEAM FLOW METER
This is inserted into the pipe in which the flow is to be measured.

are connected by a system of levers to a pen. The mercury cups are connected to the flexible tubes by hollow flexible springs. The difference of pressure in the tubes causes the mercury to flow from one cup to the other until the system reaches a condition of equilibrium, thus moving the pen back and forth across the paper.

This meter can also be used for measuring compressed air, water and steam. A sample chart is shown in Fig. 3.

SPEED MEASUREMENTS

The meter used for measuring speeds, shown in Fig. 4, consists of a magneto used in connection with a low voltage graphic voltmeter. The magneto speed may be changed by using different pulleys. It is belted to the line shaft whose speed is to be measured, the voltage generated being in proportion to the speed. The relation between volts and revolutions per minute may easily be obtained and the voltmeter is then calibrated to read revolutions per minute.

This instrument is so sensitive that a change in speed of one revolution per minute may easily be shown. An instrument of this type is very valuable

Although an outfit as outlined above will cost
for investigations in silk mills, cement mills, etc., where a constant speed is desired.

Sample charts taken by the graphic ammeter and voltmeter are shown in Figs. 5 and 6.
quite a considerable sum, the accurate data obtainable will be well worth the expense. Instruments, which are to be used for this work must be accurate, rugged and portable.

After the engineer has outlined his tests and has the graphic meters all connected, his next step is to secure the necessary data. This data must be collected in an orderly manner so that he can easily refer to it and not find, after leaving, that he has forgotten some important items. A rough note book is used for each job. The next step is to index this book properly. The manner of doing this and the information required is shown below.

Preliminary—A general description of the manufacturing processes and article manufactured is given so that any engineer compiling the report will have an idea of the process.

Reasons for Making Investigation—The reasons for having an engineering report on the power plant are stated; also whether the plant is loaded to capacity or not and if the owner has under consideration the purchase of new power equipment.

General Building Conditions—The engineer must give a general description of the power buildings giving particular attention to the general state of repair and the age of the buildings. A rough sketch shows the layout of the building and the equipment in it.

Boiler Room—The following information is required:—

(a)—Boilers—

1—Number, type and horsepower.
2—Floor space required.
3—Hours of operation.
4—Steam pressure carried.
5—Cost and method of cleaning.

(b)—Coal and Ashes—

1—Kind and quantity of coal used.
2—Facilities for handling coal and cost of unloading.
3—Amount of coal kept in storage.
4—Cost of coal per ton, including freight.
5—Disposition of ashes and cost of removal.

(c)—Feed water and pumps—

1—Source of feed water.
2—Amount used and cost.
3—Scaling troubles.
4—Kind, quantity of boiler compound used and its cost.
5—Number, size and type of boiler pumps, house pumps and fire pumps.
6—Rated and operating speeds of pumps.
7—Capacity and head against which the pumps operate.
8—Hours of operation of pumps, floor space required and steam consumption. Under this division the steam tests made on the pumps with the steam flow meter are inserted.
9—Type of feed water heater and temperature of the feed water.

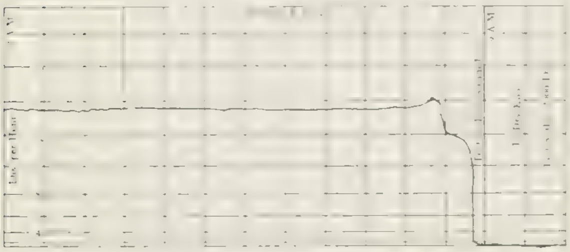

FIG. 3—CHART SHOWING A TYPICAL STEAM FLOW METER RECORD

(d)—General steam conditions—

1—All uses of live and exhaust steam.
2—Whether plant is being operated condensing or non-condensing and whether steam is being superheated.
3—Type of condensing apparatus used.
4—Source of condensing water and quantity used.
5—Vacuum used.
6—Uses of live steam other than for operating plant equipment such as engines, pumps, etc. Under this division the engineer will insert all the steam tests made in the factory to determine the steam used for manufacturing and heating purposes.

(e)—Labor—

1—The number, classification and salary of all men directly chargeable to the operation of the boiler room.
2—The quantity of labor which must be retained, if purchased power is used.

FIG. 4—A MAGNETO AND GRAPHIC VOLTMETER USED FOR ACCURATE MEASUREMENTS OF SPEED

A modified evaporation test must also be run on the boilers. A water meter is inserted in the feed water line and the water evaporated during a certain length of time is measured. During the same time the coal burned is carefully weighed. Care is taken to have the same amount of water in the boiler at the end as at the beginning of the test. This test will consume at least one day.

Engine Room—The following information must be obtained:—

(a)—Steam Prime Movers—

1—Number, type and size of engines or turbines.
2—Operating conditions and hours of operation of each.
4—Steam consumption of each engine and indicator cards from the engines.

(b)—Connected Belted Load—This following information is required in plants where electricity is not generated.

1—Amount and nature of machinery driven by prime movers.
2—Sketch of methods of drive.
3—Approximate power consumption.

(c)—Electric Generator Equipment—

1—Number, manufacturer, capacity, speed and other characteristics of all generators.
2—Whether generators are direct connected or belt driven.

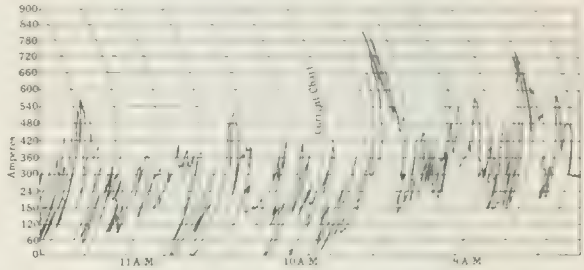

FIG. 5—CURRENT VARIATION OVER A PERIOD OF A FEW HOURS AS RECORDED BY A GRAPHIC AMMETER

3—Load carried by each generator and hours of operation. Under this division the engineer will insert all graphic charts taken by the electric meters and the readings of the integrating meters.

(d)—Connected Electrical Load—Under this division complete information must be obtained about the number, size and type of lamps used. A list of all motors must be made showing all of their characteristics. Usually a test is also made on each motor using the indicating instruments. This test is made in order to determine the proper size of motors to be applied.

(e)—Exciters and Balancer Sets—A full description of all auxiliary generating equipment is given.

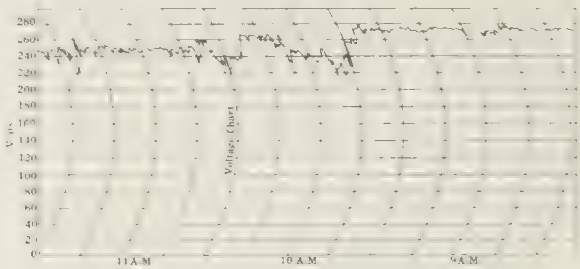

FIG. 6—TYPICAL VOLTAGE CHART TAKEN BY A GRAPHIC VOLTMETER

(f)—Switchboard—The dimensions, kind of material, number of generating and feeder panels and the number and type of instruments on the switchboard is given.

(g)—Steam or Belt Driven Air Compressors—

1—Number, type and name of all compressors.
2—Size of cylinders and revolutions per minute.
3—Air pressure and cubic feet per day.
4—All uses of compressed air.
5—Hours of operation.
6—Source of cooling water and utilization.
7—Hours of operation and charts showing steam consumption.

(h)—Labor—The same information about the labor is required in the engine room as in the boiler room.

Heating—Complete information must be obtained regarding the heating systems, heating fans and engines, heating surface installed, and the hours that steam is used. The radiators and pipes are measured and the heating surface is calculated. In winter time steam tests are made in order to determine the amount of steam required for this purpose. If exhaust steam is used in fan heaters, the amount available for heating purposes is obtained.

Cost of Plant—The original cost of the plant, itemized as much as possible, is obtained from the company's books.

Operating Expenses—The following items should be known:—

(a)—Tons of coal used and cost per ton.
(b)—Ash removal.
(c)—Water.
(d)—Labor.
(e)—Repairs.
(f)—Miscellaneous supplies.

Limitations of Present Plant—A complete description of the factors which tend toward inefficient operation should be noted. Load conditions, room for expansion and system of power distribution must also be discussed.

Recommendations—The engineer gives his recommendations for the correction of any faults he has discovered. This is a very important feature of all power investigations. A thorough investigation as outlined above cannot fail to uncover inefficiencies in the best regulated plants, and for this reason the engineer making the investigation must have a wide experience and be resourceful.

After completing the investigation, all the data collected must be worked up into such a form that it will be clear and appeal to the men to whom the report must be made. The charts and indicator cards are gone over and all the calculations are made first. Then the report is written, following an outline similar to the one given below. This outline may not fit all cases and is only given here as an illustration of the method to be pursued.

REPORT

PART ONE—PRESENT CONDITIONS

A—Description of Equipment.

B—*Steam Consumption*—The steam consumption of all the equipment is calculated on the basis of one years time and is shown under the following sub-divisions.

1—Steam used for power.
2—Steam used for compressing air.
3—Steam used for manufacturing.
4—Steam used for heating.
5—Steam used by boiler auxiliaries.

The total amount of steam used per year is then obtained and the amount is checked by using the evaporation test and total coal consumption. The percentage of steam consumed by each division is then calculated. The steam shown under division *E* is divided among the other divisions in proportion to the steam consumed by each. The purpose of dividing the steam consumed into the various divisions is to enable the boiler room costs to be distributed in the proper manner as each division should be charged with its share of the costs in proportion to the steam consumption.

C—Power Consumption—The amount of power generated is shown under this division.

D—Costs—Under this division is shown the fixed and operating expenses. These charges are divided among the various divisions, some in proportion to the steam consumption and some in proportion to the investment. The cost of each division is shown complete.

E—Cost of Power—The cost of the power is then obtained by dividing the cost of producing the power as shown under *D* by the total amount of power generated.

PART TWO—CONDITIONS WITH PURCHASED POWER

A—Equipment—Under this heading is shown the equipment recommended for the steam production, electric power and compressed air. The disposition of the equipment to be discarded and the changes recommended must be clearly shown.

B—Steam Consumption—The amount of steam which will be required for manufacturing and heating purposes must be shown under this heading.

C—Power Consumption—The amount of power which must be purchased is shown here. Any recommendations for the improvement of the operating conditions and which would reduce the power consumption are also shown.

D—Costs—First must be shown the salvage value of the equipment not needed in the power plant. The value of any other equipment which would be discarded such as direct-current motors, etc., would also be shown here. The investment in new machinery is next shown. The net amount required for making the change is then shown by subtracting the salvage value of the equipment discarded from the total investment in new machinery. Under this head is shown the fixed charges which are taken as a certain percentage of the investment.

E—Operating Expenses are worked up in the same manner as before and must show the cost of the coal required, water, labor, purchased power, repairs, and miscellaneous expenses.

F—Cost of Operation With Purchased Power—The total operating expenses are shown under this division. In addition to this the cost of the power per unit output must be shown.

G—The Summary must contain all the important information that is shown in the first and second parts of the report. The method of doing this is shown in the following summary, Table I, taken from a report of the power conditions in a large plant which manufactures sanitary ware.

This summary shows that the amount of energy required was less with purchased power than with the isolated plant. This is due to the large savings which were made in the transmission losses, and by the proper application of motors.

There are many chances for improving the efficiency and operation of a plant. If the engineer making the investigation is observing, large savings may be made and the use of purchased power will be more favorably considered. Examples of some of the savings which have been effected are given below.

TABLE 1—COMPARISON OF CONDITIONS

	Present	With Purchased Power
Investment	$ 31 842	$ 8 930
Difference in investment with purchased power	....	22 912
Percent difference	....	72
Yearly expenses (not including fixed charges	19 531	12 185
Saving in expense	....	7 346
Percent of savings	....	37.6
Yearly expense (including fixed charges	23 352	13 165
Saving in expense	....	10 187
Percent of saving	....	43.7
Kilowatt-hours required per year	643 129	630 800
Saving in power	....	12 329
Cost of power per kw-hr.—based on total expenses	0.0363	0.0209
Not including fixed expenses	0.0304	0.0193
Percent of saving on net investment	....	82.4
Percent of saving on total investment	....	63
Years required to pay for total investment	....	1.6

At one plant the steam flow meter indicated a large waste of steam in a line which was supplying the steam for office heating. Upon investigating, the engineer found that the pipe was very leaky and the steam was escaping in this manner. Fig. 7 shows the steam rising from the ground from these leaks.

In another factory the steam meter enabled the engineer to discover the fact that the steam traps were not operating properly. An auxiliary steam jet which was being used to remove the entrained water from the trap was found to be consuming five percent of the total amount of steam generated by the boilers and was costing the company $1 600 a year to keep in operation. The installation of the proper kind of traps eliminated this waste.

FIG. 7—A PHOTOGRAPH SHOWING THE STEAM LOSS FROM A LEAKY HEATING SYSTEM

Central station managers are coming to realize that it is to their advantage to show shop managers how to reduce their costs by introducing more efficient methods. In other words they sell utility and make each unit of power produce the the maximum value, even though the number of units sold is decreased. They receive their reward in having satisfied customers on their lines and in securing future business without question.

Motor-Driven Shovels

W. H. PATTERSON

A LARGE NUMBER of electrically-operated shovels are now in successful operation both in this country and abroad, in stone quarries, gravel pits, brick and tile yards, metal mines and grading operations. The shovels are similar to the standard steam shovels, using the ordinary dipper on the end of a boom and having three separate and distinct operating parts, known respectively as the main hoist, swinging boom, and thrusting boom. The main hoist motor varies in size from 35 to 250 horse-power; the swinging boom motor from 15 to 100 horse-power; and the thrust motor from 20 to 135 horse-power.

The hoist motor on an electric shovel performs simply ordinary hoisting work of a very severe character. The majority of the work is at high torque and low speed and the motor will be stalled frequently when the shovel is digging in hard rock. Both the motor and controller must be designed to withstand such severe service, but this can readily be done by proportioning the torque and radiating capacity of the motor to the work to be done and furnishing a controller, together with proper resistance to allow maximum work being obtained from the motor without danger of burning it out. The motor must be designed so as to permit quick acceleration and instant braking, also to withstand what is commonly termed "plugging," and severe vibration.

The duty of the swing motor is not exceptionally severe. It consists simply in revolving the turn-table carrying the main boom of the shovel.

The thrust motor has the most severe service,

in most cases, of any part of the electrical equipment on the shovel. The motor makes comparatively few revolutions during each part of the cycle and must exert its maximum torque at practically stand-still. When running at high speed its torque will always be

FIG. 1—EIGHTY TON BUCYRUS SHOVEL AND ELECTRIC DRAG LINE
Both operated by wound secondary induction motors, in the gravel pits of the United States Reclamation Service, Lahonton Dam, Nevada.

light. It is subject to frequent stalling and its torque must not diminish when so stalled. It is often stalled for a minute or more at a time, and is provided with a preventive resistance which will limit the current drawn with the motor at a stand-still. The thrust motor is usually connected through a slipping friction clutch which will hold up to a point corresponding to nearly the maximum torque of the motor, but which

FIG. 2—EIGHTY-FIVE TON BUCYRUS SHOVEL
Operated by wound-secondary induction motors.

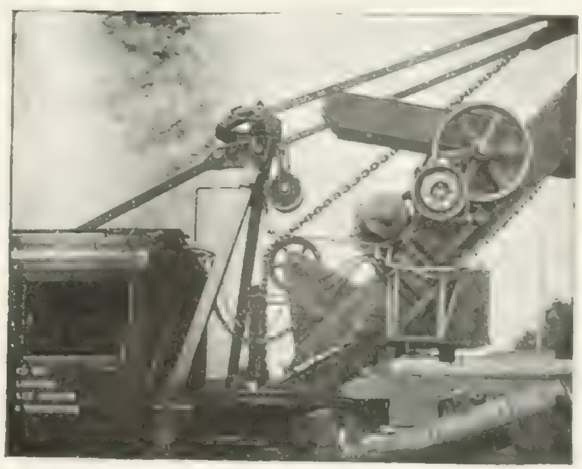

FIG. 3—DETAIL VIEW OF SHOVEL
Showing thrust motor.

will still permit the motor to revolve slowly if an object requiring excessive torque is encountered.

Shovels are usually equipped with air-operated brakes to stop the motor and hold the load. The clutches are also air-operated. For supplying air to the clutches and brakes a small motor driven air compressor, similar to that used for air brake equipments on electric railway cars, is usually installed on the shovel.

Both alternating and direct-current drive have been used successfully on shovels, having dippers varying in capacity from 0.6 to 3.5 cubic yards The largest and most successful have been for alternating current in mines and stone quarries where only alternating current was available. All electric shovels use low voltage motors, i. e., 600 volts or lower. Provision is usually made for mounting transformers on the rear of the shovel to step down from any ordinary distributing voltage to the proper motor voltage.

Each motor is controlled independently of the others. On smaller shovels, requiring motors of not over 50 horse-power in capacity, ordinary drum reversing controllers are used, while on larger shovels, magnetic switch controllers are used, operated from master switches. The controller panels and resistors

are mounted in the rear of the shovel, while the master switches are mounted in the front at a convenient position for the operator.

The principal advantages of the electric shovel over the steam shovel are:—

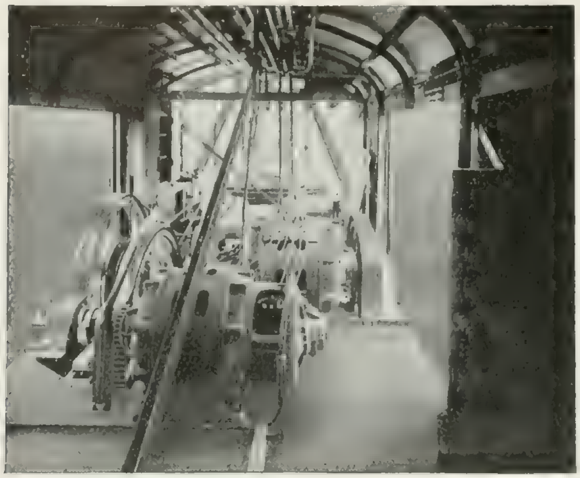

FIG. 4 VIEW OF CAR INTERIOR
Showing hoist and swinging boom motor

1—The machine requires only one or two men and the men need not be skilled engineers or firemen, while three or more are generally employed on a steam shovel.
2—The hauling of coal and water is avoided.
3—Boiler troubles are entirely eliminated.
4—No delay is ever occasioned due to waiting to steam up, as the motor is always ready to start.
5—There is nothing to freeze up in cold weather.
6—There are no stand-by losses; the motor driven shovels carry no power expense whatever when not running.
7—The fuel economy is very much higher, as central station circuits offer a very economical source of power.

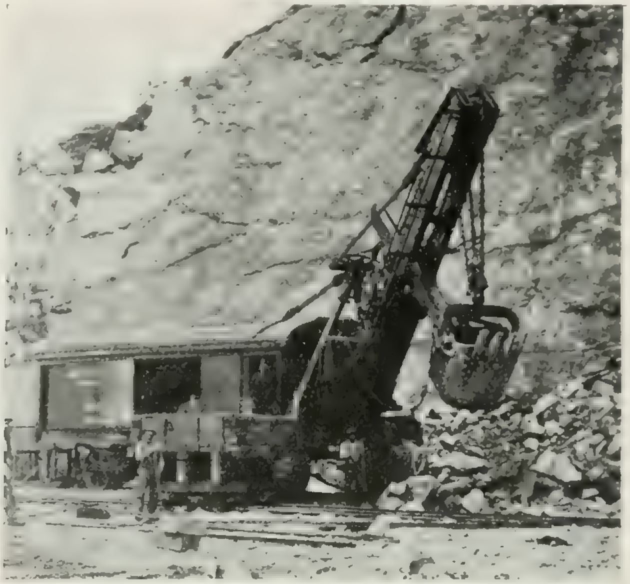

FIG. 5 MOTOR-DRIVEN SHOVEL IN A STONE QUARRY

8—The quiet operation of the electric shovel and the absence of smoke makes this type especially suitable for city work.
9—The extreme compactness of an electrical equipment is especially noticeable on large shovels.

Power Requirements of Electric Hoisting Plants

WILFRED SYKES

IN THE CASE of small and medium sized hoists it is often difficult to determine upon definite operating cycles, although generally the maximum load to be hoisted is fairly well known. In such cases the size of the motor is usually determined from the formula:—

$$\text{Horse-power} = \frac{\text{Total unbalanced load in lbs} \times \text{hoisting speed in ft. per min.}}{33\,000 \times 0.8}$$

The overall efficiency of the mechanical parts of the equipment is taken at 80 percent.

As the services is intermittent and during the intervals between trips the motors have an opportunity to cool, it is not necessary that the motor should be capable of carrying the load as determined above continuously, and in order to preserve a good balance between the maximum torque capacity of the motor and its heating capacity, motors with intermittent ratings are used for such hoists. It has been found by experience that if a motor has a capacity sufficient to carry the load as determined above for one-half hour, it will be large enough to operate the hoist under ordinary conditions. In cases of very severe service, where the hoist operates a large percentage of the time, such a simple rule cannot be used and such propositions must be worked out in greater detail.

Direct-current motors for such hoists are generally series wound; for alternating-current, slip-ring induction motors are always employed. Such induction motors are designed for high momentary overload capacities, necessitating high magnetizing currents and consequent heating if run continuously even at light loads.

For large hoists, the cycle of operations is usually well defined, and the required motor rating can be accurately determined. This complete cycle consists of six different periods, namely, acceleration, constant speed and retardation in both directions. The parts of the hoisting equipment to be considered in selecting a motor are the hoist drum, sheave, rope, cage or skip, the car and material to be hoisted, and the motor armature.

The following symbols will be used in the discussion. Unless otherwise stated, all weights are in pounds, dimensions in feet, time in seconds, and torque in pounds-feet (lbs-ft.).

A—Acceleration torque at drum shaft.
B—Retardation torque at drum shaft.
C—Weight of cage or skip.
c—Weight of car.
D—Depth from which material is hoisted.

F—Friction torque required for complete hoist mechanism.
I—Moment of inertia $= \frac{Wr^2}{g}$.
L—Weight of material hoisted.
L_1—Total unbalanced weight hoisted.
M, M_1, M_2, etc.—Torque at drum shaft during different parts of a hoisting cycle.
N, N_1, N_2, etc.—R.p.m. of drum, sheave and motor armature, respectively.
R—Radius of drum.
r—Radius of gyration.
S—Total weight of rope.
s—Weight of rope per foot.
T—Total time of hoisting.
t—Time of hoisting at full drum speed.
t_1—Time of acceleration.
t_2—Time of retardation.
V—Maximum rope speed in feet per minute.
v—Maximum rope speed in feet per second.
ω—Angular velocity $= \frac{2\pi N}{60}$.

Considering the simplest proposition first, an unbalanced hoist, the torque to sustain the total load at rest at the bottom of the hoist is $(L+C+c+Ds)R$. The torque to start this load upward must exceed the torque at rest by the amount necessary to overcome the friction of the bearings, gears, sheave, wheel, guides in shaft, and air, and also to accelerate, or

$$M_1 = (L+C+c+Ds)\,R+F+A$$

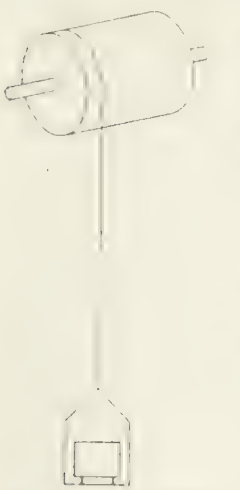

FIG. 1—DIAGRAM ILLUSTRATING SIMPLEST FORM OF HOIST

As the hoist is gradually brought up to speed a portion of the rope is wound on the drum and the load is reduced by a corresponding amount. If the rate of acceleration is constant, the average speed of the hoist during this period will be $V_{av} = v \div 2$. The torque on the hoist has been reduced, therefore, by an amount corresponding to $\frac{vt_1s}{2}$ *R*, or in other words the torque will be,—

$$M_2 = (L+C+c+Ds-\frac{vt_1s}{2})\,R+F+A$$

As soon as the full speed is attained the acceleration comes to an end and the torque is decreased by an amount corresponding to the accelerating force and at this point becomes,—

$$M_3 = (L+C+c+Ds-\frac{vt_1s}{2})\,R+F$$

During the period of full speed the rope is wound on the drum at a constant rate and the load is uniformly reduced until there remains suspended only the amount of rope corresponding to the distance travelled during retardation, and at this point the torque is,—

$$M_4 = (L+C+c+\frac{vt_2s}{2})\,R+F$$

During the accelerating period energy was stored in the moving parts; as soon as retardation begins, the effective torque at the drum shaft is reduced by an amount corresponding to the energy given up by the moving parts, or in other words,—

$$M_5 = (L+C+c+\frac{vt_2s}{2})\,R+F-B$$

At the moment of stopping when the cage has reached the landing stage the torque will be,—

[illegible]

In the case of a simple hoist, as illustrated in Fig. 1, some arrangement must be made for lowering the empty cage, it being controlled either by the mechanical brakes or by some form of electric braking. In any case it is desirable to know how much torque must be provided during lowering, as in some cases this lowering torque seriously affects the size of machine required.

During the accelerating period, when energy must be stored in the moving parts to cause them to accelerate, the effective torque at the drum shaft will be, at the start,—

[illegible]

Friction always tends to retard motion and in this case, where work is being performed by the descending load, the torque at the shaft that must be absorbed by the braking arrangement is reduced by the amount required to overcome the loss in the machine itself. At the end of the accelerating period the torque has been increased by an amount corresponding to the length of rope that has been unwound so that at this point it is

[illegible]

At the beginning of constant speed, the effective torque is increased by an amount equal to the accelerating force, and therefore,—

[illegible]

At the end of the constant speed period the load will be,—

[illegible]

During retardation the energy stored in the moving parts will be given up and the torque at the drum shaft will be increased correspondingly so that at the beginning of this period it is,—

[illegible]

At the end of retardation the torque is,—

[illegible]

From the above equations a load diagram can be calculated.

TIME

As usually presented, the problem is to obtain a certain output in a given time, which is so set as to allow for unavoidable delays that always occur. The total time that the hoist is in motion is made up of the constant-speed period, accelerating period, and retarding period; assuming that the rate of acceleration and retardation is constant, the full hoisting speed can be obtained when the time for starting and stopping has been determined. There are certain practical limits which must be taken into consideration when the available time is very short, but usually these limits are not approached with the ordinary hoist. As long a time as possible should be allowed for starting, and the rate of retardation should be fixed by the time that is required to make a good landing.

The accelerating period should not be too long, however, as the operator will not be bothered by starting so slowly unless automatic control is provided, so that the human element must be also considered. Assuming that a certain time, $t_1 + t_2$ has been allowed for starting and stopping the full speed will be,—

$$V = \frac{D}{T - \left(\frac{t_1 + t_2}{2}\right)}$$

If the full speed is fixed, the time available for acceleration and retardation will be,—

$$2\left(T - \frac{D}{V}\right)$$

The actual division of the hoisting time is largely a matter of experience, especially when the time available is very short. Whether it is more economical to increase the time for starting and stopping and to allow a longer constant-speed period, thereby giving a lower maximum speed, or to increase the maximum speed and allow a slower rate of acceleration and retardation is a question that depends upon local circumstances.

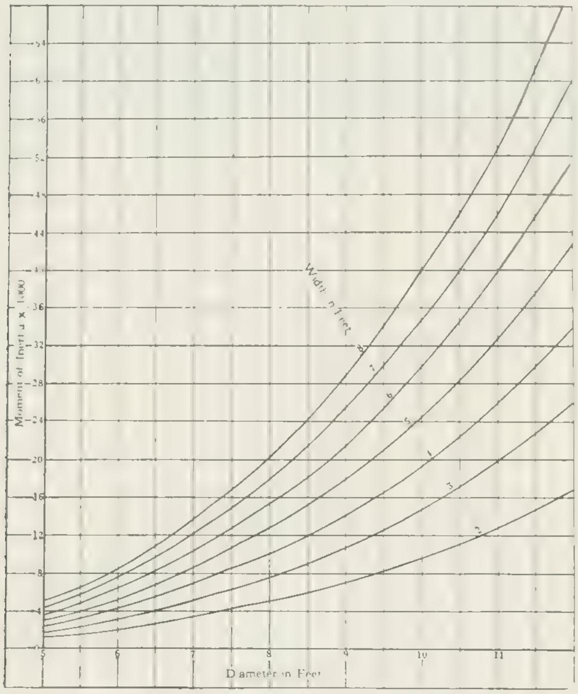

FIG. 2—CURVES INDICATING VALUES OF INERTIA FOR VARIOUS SIZES OF CYLINDRICAL DRUMS

ACCELERATION AND RETARDATION

The torque required at the drum shaft to accelerate or retard the moving parts depends upon the mass and the rate of speed change. In practice, it will be found convenient to obtain the equivalent moment of inertia of all moving parts at the drum shaft, which can be readily done, as it is proportional to the square of the speed. The total inertia is made up of that of the travelling parts, such as cage load, rope etc., and of the rotating parts such as drum, sheave, motor, etc. The inertia of the mechanical parts of the hoist varies greatly with the different builders, and when possible, actual figures should be obtained. In the preliminary design of a hoisting installation no information is available on such features, and Figs. 2 and 3 show the average inertia of drums of various sizes, cylindrical and conical respectively. The inertia of the traveling parts, such as rope, is easily obtained, as the radius of gyration is the radius of the drum. The sheave is comparatively unimportant but its inertia is given approximately by the following formula:—

$$I_s = 7R^3$$

where R = radius of sheave in feet.

The inertia of the motor is more difficult to estimate, as at this stage of the calculation the size required is not definitely known, but an approximate estimate can be made from the load and speed.

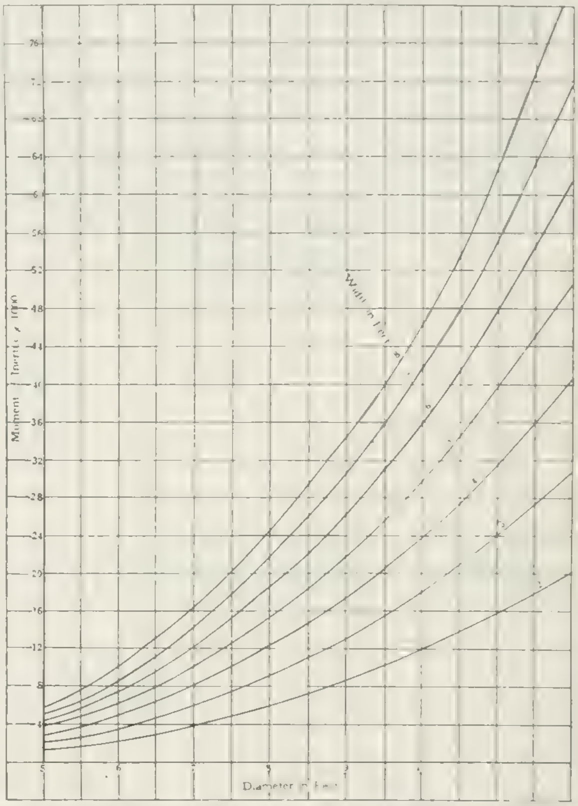

FIG. 3—CURVES SHOWING VARIATION OF INERTIA WITH SIZE OF DRUM FOR CONICAL DRUMS

It is not possible to give any general rules for the inertia of motors as it varies greatly for different designs, types, speeds, etc., and consequently special inquiry is necessary in every case. The inertia of any gearing that may be used is not very great and generally will not exceed 10 percent of that of the drums.

The total inertia reduced to the drum shaft is, therefore,—

Drums—See Figs. 2 and 3.

Traveling parts — $\frac{(L + C + c + S)\, R^2}{32}$

Sheaves — $7\, R^3 \left(\frac{N_1}{N}\right)^2$

Motor — $I_m \times \left(\frac{N_2}{N}\right)^2$

Where N = full speed of drum in r.p.m.
N_1 = full speed of sheave in r.p.m.
N_2 = full speed of motor in r.p.m.
I_m = Moment of inertia of the motor = $\frac{Wr^2}{g}$

The total moment of inertia, I_t, enables the accelerating torque to be readily obtained. The angular acceleration is,—

$$\omega_1 = \frac{\frac{2\pi N}{60}}{t_1} \text{ and the angular retardation } \omega_2 = \frac{\frac{2\pi N}{60}}{t_2}$$

The accelerating moment $A = I_t \times \omega_1$, and the retarding moment $B = I_t \times \omega_2$.

The friction load depends upon a great many factors such as the condition of shaft, cage, sheaves, hoist, etc., as well as the weight of the various parts, and the speed. The air friction of the cage in the shaft is considerable in the case of high-speed hoists and should be considered. Experience has shown that in the case of a vertical hoist with a direct-connected motor, the total friction is equal to about five percent of the weight of the traveling part, such as ropes, load, cages and cars. In the case of a general hoist, about 7.5 percent is a fair figure.

The application of the formula may be better understood by working out a simple case; it being assumed that the following information is given:—

Net load, 5 000 pounds.
Depth, 1 000 feet.
Cage, 4 000 pounds.
Car, 2 500 pounds.
Rope, 1⅛-inch diameter, 2 pounds per foot.
Interval for loading and unloading, 15 seconds.
Time per round trip, 2.5 minutes.
Drums, 8 feet diameter, 5 feet wide.
Sheave, 8 feet diameter.
Time, net hoisting time, 1 minute.
Assume acceleration 10 seconds. Retardation 10 seconds.

$$\text{Maximum hoisting speed} = \frac{1000}{60 - \frac{10 + 10}{2}} = 20 \text{ feet per second.}$$

$$\text{Maximum speed of drum} = \frac{20 \times 60}{8\pi} = \text{approximate, 48 r.p.m.}$$

$$\text{Distance traveled during acceleration} = \frac{20 \times 10}{2} = 100 \text{ feet.}$$

$$\text{Distance traveled during retardation} = \frac{20 \times 10}{2} = 100 \text{ feet.}$$

Inertia—Drum I = 13 000
Sheave $= 7\ R^3 =$ 450
Traveling part $\left(\frac{5000 + 4000 + 2500 + 2000}{32}\right) 4^2 =$ 6 750
Motor geared 5:1 ratio, about 300 hp.
I = [illegible] 000 [illegible] 000 $\left(\frac{240}{48}\right)$ [illegible] = 15 000
Total inertia $= I_t =$ 35 200
Angular velocity $= 2\pi N \div 60 = 5$.
Angular acceleration $5 \div 10 = 0.5$.
Angular retardation $5 \div 10 = 0.5$.
Accelerating moment $= A = 35\,200 \times 0.5 = 17\,600$ lb-ft.
Retarding moment $= B = 35\,200 \times 0.5 = 17\,600$ lb-ft.

Friction—Suspended load,

Net load	5 000 pounds
Cage	4 000 pounds
Car	2 500 pounds
Rope	2 000 pounds
	13 500 pounds

7.5 percent = pounds, at 4 ft. radius = 4040 lb-ft.
For convenience use 4000 lb-ft.

Torque Diagram Hoisting—

$M_1 = (5000$ [illegible] 4000 [illegible] 2500 [illegible] $2000)\ 4$ [illegible] 4000 [illegible] $17\,600 =$ [illegible] lb-ft.

$M_2 = (5000$ [illegible] 4000 [illegible] 2500 [illegible] $2000 + \frac{20 \times 10 \times 2}{2})\ 4 + 4000 + 17\,600 =$ 74 800 lb-ft.

$M_3 = (5000$ [illegible] 4000 [illegible] $2500 - 2000 + \frac{20 \times 10 \times 2}{2})\ 4 + 4000 =$ 57 200 lb-ft.

$M_4 = (5000$ [illegible] $4000 - 2500$ [illegible] $\frac{20 \times 10 \times 2}{2})\ 4 + 4000 =$ 50 800 lb-ft.

$M_5 = (5000$ [illegible] $4000 - 2500$ [illegible] $\frac{20 \times 20 \times 2}{2})\ 4 + 4000 - 17\,600 =$ 33 200 lb-ft.

$M_6 = (5000$ [illegible] $4000 + 2500)\ 4 + 4000 - 17\,600 =$ 32 400 lb-ft.

Torque Diagram Lowering—

$M_7 = (4000 + 2500)\ 4 - 4000 - 17\,600 =$ 4 400 lb-ft.

$M_8 = (4000 - 2500 + \frac{20 \times 10 \times 2}{2})\ 4 - 4000 - 17\,600 =$ 5 200 lb-ft.

M_9 = [illegible] lb-ft.
M_{10} = [illegible] lb-ft.
M_{11} = [illegible] lb-ft.
M_{12} = [illegible] lb-ft.

The power required at the motor shaft corresponding to these torques may be found from the following:—

$$\text{Hp} = \frac{M \times \omega}{550}$$

The corresponding powers for the various points on the diagram are as follows:—

HOISTING	LOWERING
M_1 = 657 hp.	M_7 = [illegible]
M_2 = 680 hp.	M_8 = 47 hp.
M_3 = 520 hp.	M_9 = 207 hp.
M_4 = 462 hp.	M_{10} = 245 hp.
M_5 = 302 hp.	M_{11} = 425 hp.
M_6 = 295 hp.	M_{12} = 433 hp.

In Fig. 4 the various points are marked, and from the foregoing it will be clear how the power required can be obtained. To obtain the size of motor, the average heating and the maximum torque required must be considered. The average heating can be obtained by taking the root mean square in the usual way. It should be noted, however, that when the motor is at rest it does not give up heat at the same rate as when running, and as all machines are rated on the assumption that they are running at their full speed and consequently being cooled at the greater rate, proper allowance must be made for this. It is usual to consider that the cooling rate at standstill is about one-half to one-third of the full-speed value, depending on the speed of the motor, so that in taking the total time of the operations to obtain the average heating, only about one-third to one-half of the interval of rest is considered.

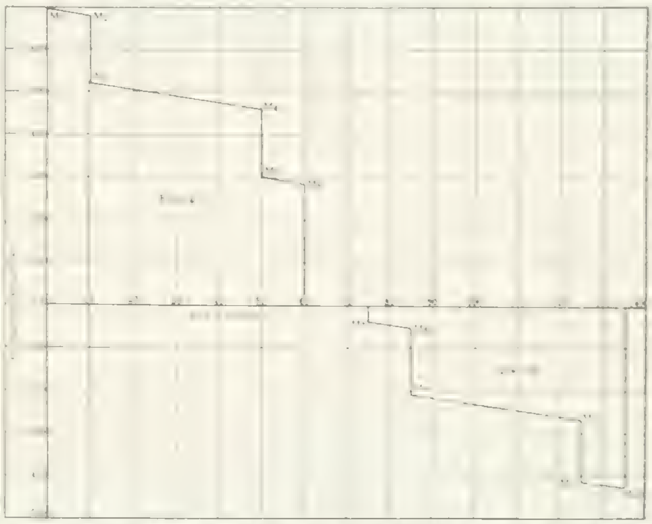

FIG. 4—[illegible]

The figures given for the corresponding horsepowers at starting and stopping are, of course, not the actual powers, as they will vary with the speed, but are the values that must be taken in determining the motor characteristics. At the moment of starting, for instance, no work is being performed but the current flowing through the windings corresponds to the power given, and on this basis the heating must be determined.

From the calculated values the heating can be obtained; only one-third of the interval of rest has been taken in the following calculation:—

$$\sqrt{\frac{[illegible]}{2 \times 60 + 2 \times \frac{15}{3}}} = [illegible]$$

From the foregoing it will be seen that the motor must be capable of developing a torque equal to 687 horse-power and of carrying 305 horse-power continuously. With an alternating-current supply, a motor with a rating of 300 horse-power continuously and a pull-out of three times full-load torque would be the right machine to use. It is necessary to have a fair margin on the peak load as a slight drop of voltage might otherwise cause the motor to stop. With direct current, the machine would have to be designed to commutate the peak load and also have the above heating capacity.

BALANCED HOISTING WITH CYLINDRICAL DRUMS

The usual arrangement for large hoists is to have two cages, one of which ascends as the other descends. The cages and cars, therefore, balance each other and the torque conditions are altogether different from those considered above.

Using the same symbols as before, the torque at the beginning of hoisting will be,—

$$M_1 = (L + Ds)\,R + F + A$$

At the end of the accelerating period the weight on the loaded side will be decreased by the amount of rope wound on the drum but from the other drum an equal quantity has been unwound so that the effective load will be reduced by an amount corresponding to twice the amount wound on the drum. The torque of the rope wound on the drum is equal to,—

$$R\frac{vt_1s}{2}.$$

so that the difference with a balanced hoist will be twice this value, or Rvt_1s The torque at this point is, therefore,—

$$M_2 = (L + Ds - vt_1s)\,R + F + A$$

At the beginning of constant speed it is,—

$$M_3 = (L + Ds - vt_1s)\,R + F$$

At the end of the constant-speed period most of the rope has been wound on the drum on the loaded side and a corresponding amount unwound with the descending cage, so that at this point the condition is the reverse of that at the end of the accelerating period and the torque required is,—

$$M_4 = (L - Ds + vt_2s)\,R + F$$

At the beginning of retardation the effective torque is reduced to

$$M_5 = (L - Ds + vt_2s)\,R + F - B$$

At the end of the trip the rope on the loaded side is all on the drum and on the other side it is all off so that the load condition is,—

$$M_6 = (L - Ds)\,R + F - B$$

To make this formula clear the same example as previously considered will be taken. Some of the factors will be changed somewhat by the greater weights of the moving parts and the inertia will be greater than with the unbalanced hoist.

Inertia 2 drums — 26 000

Traveling parts $\left(\frac{5000 + 8000 + 5000 + 4000}{32}\right) \times 4^2 = 11\,000$

2 sheaves — 900

Motor geared 5 :1, about 300 hp

$I_m = 600$ — $600 \times \left(\frac{240}{48}\right)^2 = 15\,000$

Total inertia $= I_t =$ 52 900

Accelerating moment, 52 900 × 0.5 = 26 450

Retarding moment, 52 900 × 0.5 = 26 450.

Friction Suspended load.	Net load	5 000 pounds
	2 cages	8 000 pounds
	2 cars	5 000 pounds
	2 ropes	4 000 pounds
		22 000 pounds

Friction 7.5 percent = 1650 pounds at 4 ft. radius = 6600 lb-ft.

Torque Diagram —

$M_1 = (5000 + 2000)\,4 + 6600 + 26\,450 = 61\,050$

$M_2 = (5000 + 2000 - [illegible] \times 10 \times 2)\,4 + 6600 + 26\,450 = [illegible]$

$M_3 = (5000 + 2000 - 20 \times 10 \times 2)\,4 + 6600 = 33\,000$

$M_4 = (5000 - 2000 + 20 \times 10 \times 2)\,4 + 6600 = 20\,200$

$M_5 = (5000 - 2000 + 20 \times 10 \times 2)\,4 + 6600 - 26\,450 = -6\,250$

$M_6 = (5000 - 2000)\,4 + 6600 - 26\,450 = -7\,850$

The above values correspond to the following horse-powers at the motor shaft.

M_1	555 hp	M_4	183 hp
M_2	540 hp	M_5	−57 hp
M_3	300 hp	M_6	−71 hp

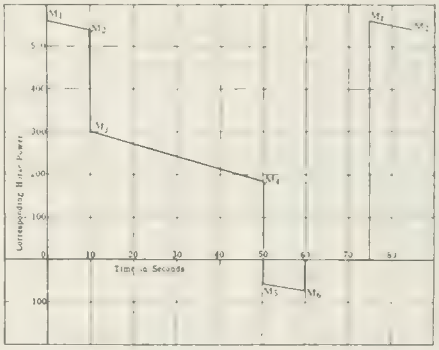

FIG. 5—LOAD CONDITIONS FOR A BALANCED HOIST, INDICATING THE POWER REQUIRED OF THE MOTOR DURING THE CYCLE OF OPERATION

The work performed during retardation is negative, or in other words the drum will drive the motor if it is retarded at this rate and this work must be absorbed by some system of braking. The motor required for this hoist would need to have a heating capacity of

$$\sqrt{[illegible]} = [illegible]$$

The maximum peak is equivalent to 555 horse-power but some margin must be allowed above this for irregularities in operation. Fig. 5 represents graphically the load conditions of this hoist.

These two examples show how the ordinary cylindrical drum hoist may be treated and this type of hoist is met with in the majority of cases. There are a great many other types, all of which, however, can be handled in the same way as indicated above with proper allowance made for the special characteristics. The characteristics of the conical drum and reel hoists are such that an accurate determination of the load diagram is rather tedious but a sufficiently close approximate estimate can be made along the same lines as indicated above.

Motors in the Pulp and Paper Industry.

E. C. Morse

MOTORS in pulp and paper mills have to operate under very severe conditions both as to location and nature of load. The severity of these conditions has often in the past been overlooked and the motors, with their control, have not been properly selected for the work. This is a matter

FIG. 1. MOTOR DRIVEN BARKER

Driven by a 15 horse-power, 680 r.p.m. squirrel cage motor.

which should be given careful attention, as paper and pulp mills operate twenty-four hours a day, six days a week, and the shutting down of any one machine may cripple the whole mill.

In a recent paper, one of the firm members of S. D. Warren & Company expressed himself as fol-

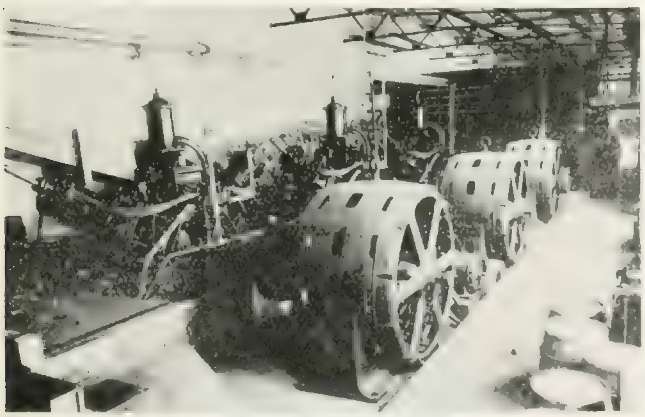

FIG. 2. THREE POCKET MOTOR DRIVEN GRINDERS

Each direct connected to a 400 horse-power, 205 r.p.m., squirrel-cage motor.

lows regarding what is required in a motor by the paper manufacturer:—

"The prime requisite from a paper manufacturer's point of view is continuity of service. To insure this the motor must be of rugged mechanical design, with ample bearings; capable of withstanding reasonable overloads for a considerable period without undue heating; accessible, so that it can easily be cleaned and, in case of trouble, be repaired easily and quickly; and must be able to hang on and not 'pull out' even under great variations of voltage. Efficiency, power-factor and starting torque are all worthy of consideration, but are not, to my mind, as important as the points above mentioned."

In order to obtain satisfactory operation a paper mill motor must be carefully chosen for its work. In general, motors driving pulp and paper machinery are located in damp places, and the windings should be impregnated to withstand moisture. Motors located in the wood rooms of pulp mills are also exposed to

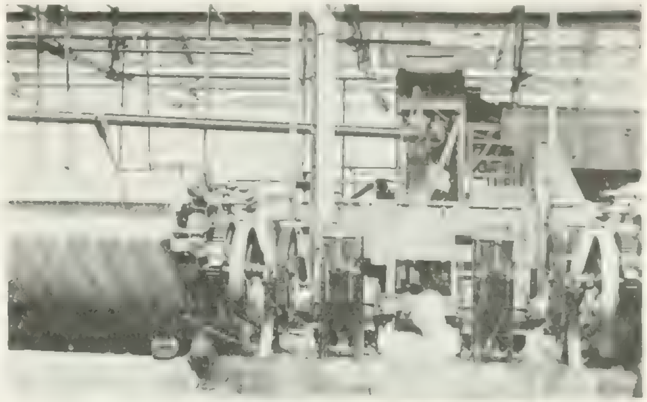

FIG. 3. EIGHTY-FOUR INCH WET MACHINES

Each driven by a ten horse-power, 840 r.p.m., squirrel-cage motor.

temperature changes. They must be able to develop a high starting torque to overcome the abnormally high static friction in machines and shafting which have stood over Sunday in a temperature in many cases far below zero. The resistance furnished with wound secondary motors should be designed for very heavy starting duty to withstand this service.

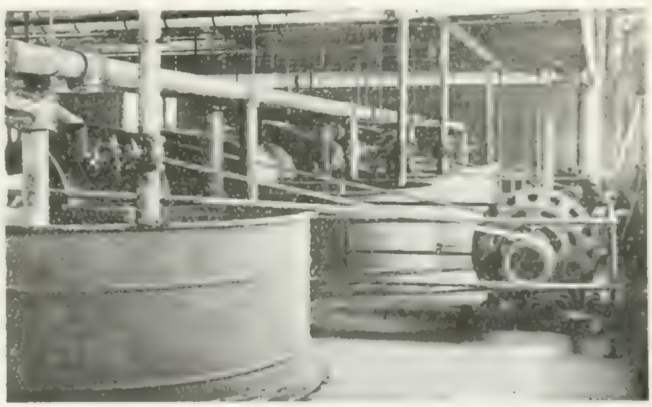

FIG. 4. [illegible]

Two beaters are driven by a 75 horse-power, 580 r.p.m., slip-ring motor.

More attention should also be paid to the type and location of control equipment than in plants operating only eight to ten hours per day; the equipment should be very rugged and of a type which may be easily and quickly repaired. Nearly all loads in pulp and paper mills either demand a high starting torque or have high peaks in their demand for power. Therefore, protective devices should be provided with inverse time element overload protection, as should also the feeder switches. In many cases a cheap

ammeter added to the motor equipment will pay for itself many times. For instance, it will show the operator whether he is using too much or not enough power, and will often serve as an indicator as to the condition of the machine. Thus, in the case of a Jordan drive it will show whem the plug needs chipping or renewing and will save the manufacturer many kilowatt hours in power consumed.

All pulp and paper mills should use alternating-current power. This is because of the simplicity of the alternating-current motor and its ability to operate under the severest conditions. The fact that it can be impregnated against moisture and will stand heavy overloads gives it a great advantage over the direct-current motor. Exception to this may be found in case of the variable speed end of the paper machine and in the finishing department (See note 6)

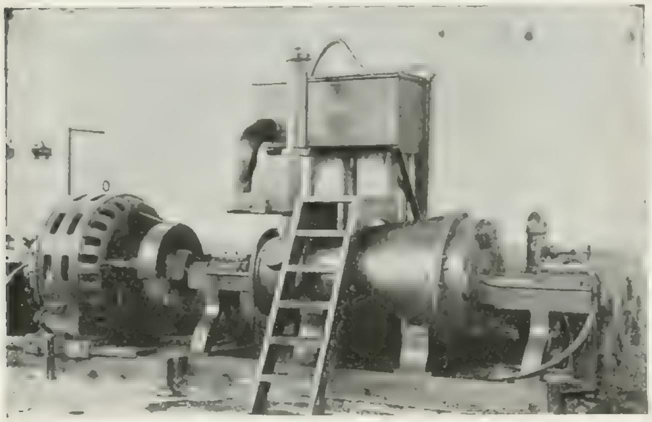

FIG. 5—JORDAN
Direct connected to a 100 horse-power, 316 r.p.m., squirrel-cage motor.

In Table I are listed the principal machines to be found in pulp and paper mills, together with the usual methods of drive when motors are used. The various special points that should be taken care of in the motor and control are indicated without any attempt being made to specify horse-power or speed requirements, which vary widely, depending on kind of pulp used, paper made and on the methods used in the particular mill.

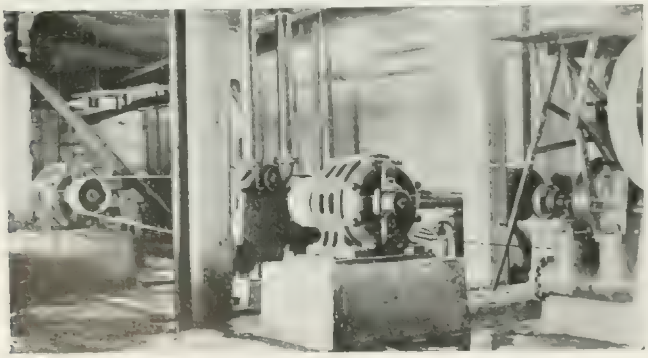

FIG. 6—CONSTANT SPEED END OF PAPER MACHINE
Belted to a 50 horse-power, 680 r.p.m. squirrel-cage induction motor.

LOW PRESSURE STEAM

There is a large demand for low pressure steam in every paper mill. It is always preferable to have this steam free from oil and in some cases it is imperative. Using high pressure steam through a reducing valve is a waste of energy. An automatic bleeder turbine will deliver automatically just the amount of low pressure steam required, free from oil, and at the pressure required for the manufacturing purposes, after having transformed into electrical power the energy in the steam between boiler pressure and the lower pressure desired. It will automatically pass any excess steam required to carry the connected electrical load, to the condenser, thus using all the available energy of the steam when it left the boilers.

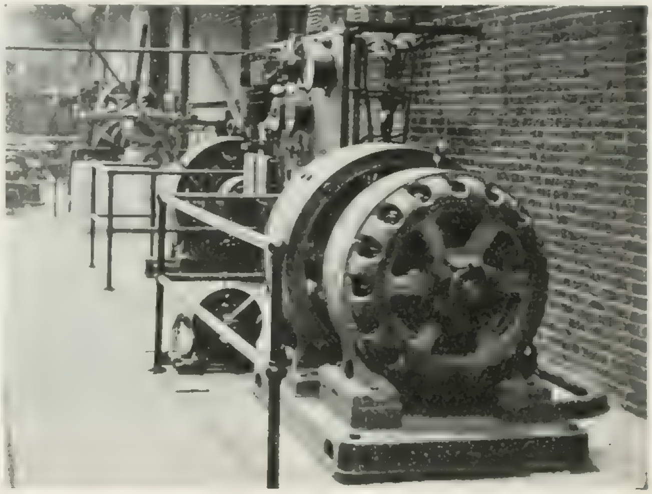

FIG. 7—DRIVE FOR VARIABLE SPEED END
Seventy-five kilowatt motor-generator set for supplying direct-current; 75 horse-power, 180-720 r.p.m. direct-current adjustable-speed motor; exciter; and push-button operated, magnetic-switch control panel.

This bleeder turbine enables the manufacturer to use electric drive on his paper machines and, without having to use steam direct from the boilers for drying, gain in speed regulation, total steam consumption, maintenance, labor and ease of control, all of which will enable him to make better paper cheaper.

FIG. 8—PUSH-BUTTON CONTROL PANEL AND SPEED INDICATOR

TABLE I—POWER CHARACTERISTICS OF PULP AND PAPER MILL MACHINERY

PULP MILL MACHINERY

Machine.	Starting Duty.	Running load.	Method of Drive.	Motor Type.	Motor Control	Remarks
GENERAL FOR ALL WOOD PULP MILLS.						
Saws	Heavy — need high starting torque	Fluctuating — high pull-out torque	Belt	Squirrel-cage Slip-ring	I. t. e. overload I. t. e. overload	If [illegible] If group drive. [illegible] changes.
Log hauls	Fairly severe	Steady	Belt or chain	Squirrel-cage	I. t. e. overload	[illegible] changes.
Conveyors	Fairly severe	Steady	Belt or chain	Squirrel-cage	I. t. e. overload	
Barkers	Fly-wheel effect	Fairly steady	Group, Direct-connected	Slip-ring Squirrel-cage	[illegible] resistance	Speed either 580 or 690 r.p.m.
Splitters	Fly-wheel effect	Fluctuating	Belted usually from group.	Squirrel-cage	I. t. e. overload	
Wet machines	Light	Steady	Belt or gear	Squirrel-cage	I. t. e. overload I. t. e. overload	
SPECIAL FOR GROUND WOOD PULP MILLS						
Grinders — 3 pocket type	Not over full load torque	Steady	Direct-connected through flexible coupling	Squirrel-cage or synchronous	I. t. e. overload I. t. e. overload	[illegible] May connect 1 to 6 to each motor
Grinders — magazine type	May have over full load torque	Steady	Direct-connected as above	Squirrel-cage or slip-ring	I. t. e. overload I. t. e. overload	[illegible] each.
Screws	Light	Steady	Belted	Squirrel-cage	I. t. e. overload	
Pumps	Light	Steady	Belted or direct-connected	Squirrel-cage	I. t. e. overload	
GENERAL FOR SULPHATE-SULPHITE-SODA PULP MILLS						
Chippers	Fly-wheel effect	Very fluctuating	Belted	Squirrel-cage large slip	I. t. e. overload	Needs motor [illegible] 3 times full load torque
Conveyors	Fairly severe	Steady	Belt or chain	Squirrel-cage	I. t. e. overload	
Screws	Light	Steady	Belted	Squirrel-cage	I. t. e. overload	
Acid plant	Light	Steady	Belted	Squirrel-cage	I. t. e. overload	
GENERAL FOR PULP FROM RAGS OR OLD PAPERS						
Rag cutters	Light	Fluctuating	Belted	Squirrel-cage	I. t. e. overload	Very dusty
Dusters	Light	Steady	Belted	Squirrel-cage	I. t. e. overload	Very dusty
Bleach boilers	Fairly heavy	Steady	Belted	Squirrel-cage	I. t. e. overload	[illegible] speed
Kollergangs or edge runners	Fairly heavy	Steady	Belted	Squirrel-cage	I. t. e. overload	Slow speed with [illegible]
PAPER MILL MACHINERY						
Pumps	Light	Steady	Belt, chain, direct-connected or geared	Squirrel-cage	Standard with I. t. e. relay	
Beaters	Very severe	Very fluctuating	Belted—group	Slip-ring	3 min. starting resistance and I. t. e. relay	May require at least twice full load torque on start
Beaters	Very severe	Very fluctuating	Belted in group with idler	Squirrel-cage	I. t. e. relay	Need only full load torque or less on start
Beaters	Very severe	Very fluctuating	Belted each to own motor	Squirrel-cage or slip-ring	I. t. e. relay also heavy starting resistance	May [illegible] torque on start
Beaters	Very severe	Very fluctuating	Two belted to own motor	Squirrel-cage or slip-ring	I. t. e. relay also heavy starting resistance	May require 1.5 to 2 [illegible] torque on start
Beaters	Very severe	Very fluctuating	Chain drive, each to own motor	Squirrel-cage or slip-ring	I. t. e. relay also heavy starting resistance	May require 1.5 to 2 times full load torque on start
Beaters	Very severe	Very fluctuating	Chain drive, two to same motor	Squirrel-cage or slip-ring	I. t. e. relay also heavy starting resistance	May require 1.5 to 2 times full load torque on start
Jordans	Light	Fluctuating	Belted to line shaft	Squirrel-cage	I. t. e. relay	Not over full load torque on start
Jordans	Light	Fluctuating	Direct-connected	Squirrel-cage	I. t. e. relay	Not over full load [illegible]
Paper machines:						
Constant speed end	Light	Steady	Belted	Squirrel-cage	I. t. e. relay	Close speed regulation wanted
Variable speed end	Severe	Steady	Belted or direct connected	Direct-current motor (See note 1).	I. t. e. relay	[illegible]
FINISHING MILL MACHINERY						
Coating machines	Fairly Light	Steady	Belted in group	Squirrel-cage	I. t. e. relay	
Coating machines	Fairly Light	Steady	Individual drive (See note 2)	D. C. or A. C. variable speed	I. t. e. relay	See note 2
Color mixers	Fairly Light	Steady	Belted in group	Squirrel-cage	I. t. e. relay	
Satin white plant	Fairly Light	Steady	Belted in group	Squirrel-cage	I. t. e. relay	
Cutters	Fairly Light	Steady	Belted in group or geared to individual motor.	Squirrel-cage	I. t. e. relay	
Calenders (web)	Fairly Light	Fluctuating	Belted in group	Squirrel-cage	I. t. e. relay	
Calenders (web)	Fairly Light	Fluctuating	Individual drive (See note 3)	D. C. or A. C. variable speed	I. t. e. relay	See note 3
Calenders (sheet)	Fairly Light	Steady	Belted in group	Squirrel-cage	I. t. e. relay	
Calenders (sheet)	Fairly Light	Steady	Individual drive (See note 4)	D. C. or A. C. variable speed	I. t. e. relay	See note 4
Platers	Fairly Light	Fluctuating	Belted in group	Squirrel-cage	I. t. e. relay	
Platers	Fairly Light	Fluctuating	Individual drive	Squirrel-cage (See note 5)	I. t. e. relay	See note 6

I. t. e. means inverse time element.

NOTE 1—PAPER MACHINE DRIVE, VARIABLE SPEED END

Using steam engine or line shaft drive on the variable speed end of paper machines in the past, the speed variation has been obtained by the use of chain gears, step cone pulleys, plain cone pulleys, Moore & White variable speed drive or Reeves variable speed drive. If alternating-current motors are used to drive the variable speed end, any one of the above variable speed devices may be used in connection with the motor, in which case a standard squirrel-cage type of motor is satisfactory.

The variable speed end of newspaper machines has been driven successfully by the use of resistance type alternating-current motors, obtaining the speed range by a drum controller and resistance. This method of drive is not satisfactory in most cases if the speed variation desired is more than 20 percent. This is due to the close speed regulation with a slightly fluctuating load which is required on the paper machine.

If a wider variation than 20 percent is desired, the best and most satisfactory method of obtaining this speed range when the variable speed end of the paper machine is electrically driven, is by the use of a direct-current adjustable or variable speed motor. The speed range required on the variable speed end of paper machines varies from 15 or 20 percent up to a speed range of 10:1. Any desired speed range within the above limits can be taken care of satisfactorily by the use of a direct-current motor.

The best method of securing such an extreme range of speed control is to belt or direct connect a direct-current adjustable speed motor to the variable speed line of the paper machine, as shown in Fig. 7, this motor to obtain its power from a direct-current generator of proper capacity for this individual motor. The field of this direct-current generator and the field of the direct-current motor should be separately excited from a small exciter, which may be belted or direct connected to the generator. The higher speeds are then obtained by reduced excitation of the motor and the very low speeds by reduced excitation of the generator and maximum excitation of the motor. The generator referred to may be driven by an alternating-current motor as a part of a motor generator set, or by an engine or by a steam turbine. If driven by an alternating-current motor, this latter should preferably be of the synchronous type, in order that the speed regulation of the motor may be the best possible.

The control of the variable speed motor may be handled entirely from a push button station, such as shown in Fig. 8, which, used in connection with a magnetic type starter and a motor operated field rheostat, makes the control entirely automatic and the operation about as follows:

Push the start button—motor accelerates to a minimum running speed.

Push the fast button—motor accelerates to desired operating speed as shown on the speed indicator.

Push the slow button—motor slows down any desired amount.

Push the stop button—motor at once stops.

The user has two alternatives in connection with the setting of the speed controller on stopping the motor. The first method causes the speed regulator to be automatically turned to maximum field position, so that the motor on again starting up will accelerate to its minimum operating speed. The second method leaves the speed regulator set, and the motor on again starting automatically accelerates to the previous operating speed.

Another modification of the above control, reducing the cost somewhat and just as satisfactory on a small machine, is to eliminate the automatic feature on the speed control, making the starting and stopping from a push button station only, and the speed control from a hand operated regulator on the control panel.

NOTE 2—DRIVE OF COATING MACHINES AND WINDER

In order to obtain the maximum production from any given coating machine, it is of great advantage for the operator to be able to vary the speed over a considerable range, and of course the winder speed must be varied over the same range. As both coating machines and winders are primarily constant torque propositions, it is possible to use an alternating-current variable speed motor for this work. If direct-current is available, a much simpler, more efficient and more satisfactory drive can be obtained by the use of direct-current adjustable speed motors. The direct-current motors may be equipped with automatic starters with push button control for starting and stopping and a hand operated speed regulator.

NOTE 3—DRIVING OF WEB CALENDERS

To operate web calenders successfully the following conditions must be met:

A—Obtain a uniform "threading in" speed, which is usually about one-tenth to one-twelfth of normal running speed.

B—Obtain smooth acceleration from "threading in" speed to maximum speed.

C—Must be possible to easily and quickly slow down and again accelerate to operating speed.

D—Must be able to operate at various speeds, from 50 to 100 percent of maximum speed in order to accommodate various grades and conditions of paper.

E—Should be able to shut down motor from various points about the calender.

F—Control should be simple and extremely reliable.

G—Quick stopping of calender should be obtained. The slow or threading in speed may be obtained by the use of a small separate motor with proper gearing and clutches, or by the use of proper clutches and gearing in connection with the large motor used for operating at the high speed. If a small motor is used for the slow speed, it should be of the squirrel-cage type for alternating current, and if for direct-current, of the shunt-wound type.

For the large motors, if alternating current is used to drive the calender, a slip-ring type can be used with a drum controller and resistance, so designed that the speed may be reduced from maximum to approximately one-half at full-load torque. The primary of this motor should be controlled by solenoid operated switches which in turn may be operated from push buttons located around the calender, and should also be so interlocked with the drum controller that the controller must always be returned to the *off* position before the solenoid switches can again be closed.

If direct-current motors are used, the large motor should be of the adjustable-speed type, based on approximately constant torque duty with a speed range of 2:1. The starting and accelerating of this motor should be automatic by means of magnetically operated switches which may be operated from push button stations located around the calender and so interlocked with the speed regulator that they cannot be closed until the speed regulator is returned to the *off* position: or the speed regulator should be equipped with field relays in order that the motor cannot be started on a weak field.

NOTE 4—DRIVE OF SHEET CALENDER

Sheet calenders require constant torque over a range of speeds, and to obtain maximum production it should be possible to vary the speed from maximum to 50 percent of maximum. The power required for sheet calenders is much less than for web calenders, and slip-ring type motors equipped with drum controllers and resistance for continuous operation on any notch, and for reducing the speed to one-half maximum, based on constant torque operation, can be used satisfactorily. If direct-current motors are used they should be of the adjustable speed type with approximately a 2:1 speed range based on a constant torque rating; the controller may be hand operated both for starting and regulating as it can be mounted adjacent to the operator's position.

NOTE 5—PLATER DRIVE

The load on a motor driving platers individually is very fluctuating, and these high peaks of load occur several times a minute while the plater is in actual operation. The only successful method to date of driving platers by individual motors, consists of a motor carrying a beveled pinion on the motor shaft, meshing into bevel gears which are alternately thrown on and off by means of friction clutches operated hydraulically; in order to assist this motor in its work it should have a fairly high slip and carry a small flywheel on the opposite end from the bevel pinion, and should preferably have an outboard bearing outside of the flywheel.

NOTE 6—COATING AND FINISHING ROOM MACHINERY REQUIRING VARIABLE SPEED

There are many advantages to be derived by the use of adjustable speed direct-current motors over alternating-current motors in connection with this type and class of machinery, which may be briefly stated as follows::—1—Control of motors simpler and more easily worked out; 2—automatic speed control by means of push buttons if desired; 3—more intermediate speed steps between minimum and maximum speed; 4—dynamic braking can be used for quick stopping of machine; 5—greater torque available at minimum speed than at maximum; 6—close speed regulation at any speed setting, even though the torque is changed; 7—if motor is operated at lower speed for any considerable amount of time, a material saving in power is obtained.

It is therefore often advisable to very seriously consider the installation of direct-current in the finishing and coating departments of a paper mill, even though alternating-current should be used in the remainder of the plant.

The Field of the Storage Battery Locomotive

W. M. Robbins

INTEREST in the application of storage batteries to locomotives has become widespread since the development of the present rugged types of storage cells, and a well founded faith exists in their advantages with respect to safety, convenience and economy for industrial and mine service. It is well known that there is a big field for machines designed with the right characteristics and equipped with the right batteries. That the boundaries of this field of application are hazy to many has been shown by the flood of inquiries sent to manufacturers and consulting engineers, for information on locomotives from one-half to 75 tons in weight, which wide range covers many conditions where success would be met and, on the other hand, conditions where some other form of electric haulage would be decidedly more desirable. It is the object of this article to indicate where this type of locomotive may be recommended, by giving brief illustrated descriptions of machines actually built, by outlining the deciding factors in a consideration of correct applications, and also what sizes of locomotives are in greatest demand, as indicated by manufacturers standards.

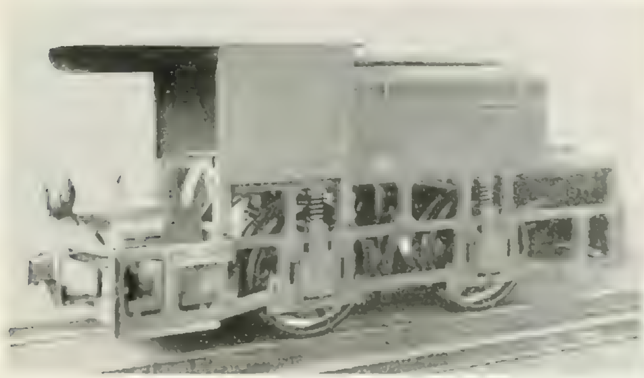

FIG. 1. A THREE TON BAR-STEEL FRAME INDUSTRIAL LOCOMOTIVE

For handling ash cars in power plant of a traction company. Equipped with an 80 volt motor, with fields divided in halves for benefit of series-parallel control. Hood for protection against dripping water. Gauge, 26 inches; height, 48 inches; battery, 40 cells of Iron-Clad Exide, MV-9, capacity 216 ampere-hours.

FIG. 2. A 3.5 TON BAR-STEEL FRAME LOCOMOTIVE

For service in metal mines having a slight, uniform grade in favor of loaded cars. Equipped with two 80 volt motors with divided fields permitting full benefit of series-parallel control. Motors suspended towards couplers to allow inspection of commutators without removing battery. Gauge, 24 inches; height, 46 inches; battery, 70 cells, Edison A-4, capacity 150 ampere-hours.

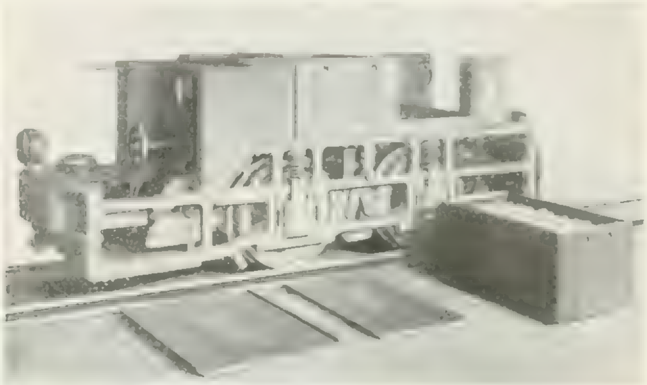

FIG. 3. LOCOMOTIVE WITH TRAYS OF CELLS ASSEMBLED IN MORE THAN ONE BOX

To decrease the weight of battery to be handled at one time.

Appreciation of the advantages of electric haulage over manual, animal, compressed air, internal-combustion and other motive powers, has led a few to believe that the storage battery locomotive is a cure-all, that is, will do anything a trolley locomotive of equal weight will do and without the complication of a trolley wire. Second thought shows that the battery, being a portable power-plant, has a comparatively low limit to its capacity. With the storage cell in its present state of development, no one would recommend it for the almost continuous main haul service in coal mines, where trolley locomotives of from 10 to 30 tons in weight are used, operating over heavy grades at the high speeds (for this work) of seven to ten miles per hour. In many cases where it is not so easy to decide between trolley and battery, the local condition must be studied in detail.

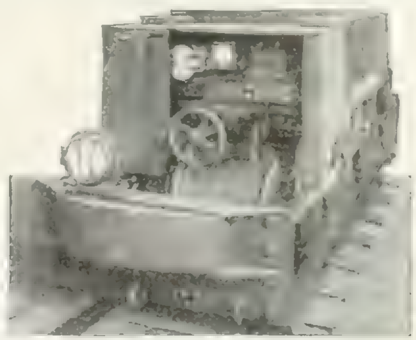

FIG. 4. FRONT END VIEW OF 3.5 TON BAR-STEEL MINE LOCOMOTIVE

Showing accessibility of motor and convenient location of panel on which are mounted meters and switch.

Haulage propositions may be classified as follows:—

1—Those cases where it is obvious that only trolley locomotives will be feasible.

2—Those cases where obviously only the battery locomotive will be feasible.

3—Those cases where the choice depends on a careful study of the relative advantages in connection with local conditions.

In coal mines the limited space, the large amount of power required and the steady all-day duty over long hauls, practically eliminates the possibility of using storage cells; this is an example of Case *1*.

Under Case *2* come locomotives operating within factories, shops, tunnels, or navy yards, boiler-rooms, etc., where a trolley wire would be dangerous or interfere with cranes, or the like. This class usually requires locomotives of from 2.5 to 7 tons in weight, and capacities of battery which can be applied without difficulty to meet the various requirements of weight, dimensions, charging and discharging voltage. A typical machine of this class is shown in Fig. 1.

In Case *3*, there may be no objections to trolley wire, or no choice between the convenience of the two types; economy being usually the main consideration. Examples are, outdoor switching in various industrial works, metal mine haulage, coal mine gathering, etc. Of course, the comparison must include every part of the system contributing to the haulage costs. A trolley locomotive is, in itself, more rugged, less complicated, lower in price and more desirable; requires no attention after the days work, except occasional inspection and over-hauling; can operate double shift when occasion demands, without regard to a predetermined kilowatt-hour consumption limit; and has a longer life than a battery locomotive. On the other hand, a storage machine is self-contained; can utilize power available at night, when the load on the generators is light; and saves the labor and material costs of bonding rails and installing trolley wires and feeders. Each individual case is to be decided independently of others.

The battery locomotive has been adopted in many metal mines and ore transportation tunnels because the grades are uniform and about one-half percent in favor of loads. Much attention is being given to gathering service in coal mines, where great savings have been made over animal power by locomotives operating on trolley wire in the branch entries, and employing cable reels to get the cars from the rooms where no trolley is installed. The grades are often heavy and against the loads. Still greater savings could be effected by eliminating the trolley wires, bonding and labor of installation, provided storage locomotives could be built within the dimensions and weight limits required in a mine and of sufficient kilowatt-hour capacity to operate all day, (with possibly a half-hour boost at noon) under the severe conditions existing in mines. In many cases it has been determined that to do about the same work as a five-ton trolley gatherer (which replaces a number of mules) in hilly mines, would require a storage capacity that would make it impossible to get the battery locomotive within the dimension limits, or keep the weight down near that required for adhesion. On the other hand there are many cases where well proportioned locomotives, (with regard to weight, motors and battery) can be used to great advantage. Incidentally, it will often be found desirable to use a battery gatherer of the capacity of two or three, rather than eight or ten mules.

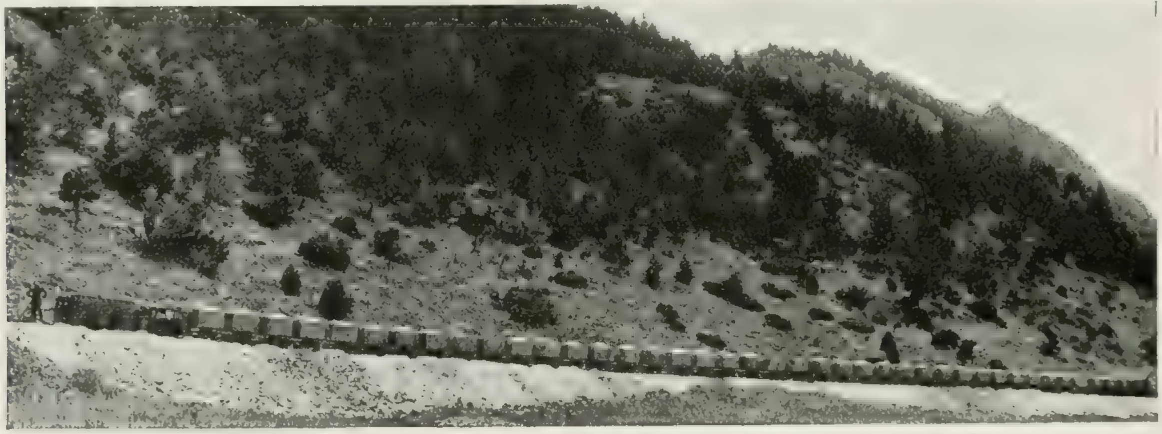

FIG. 5 A FOUR TON, 24 INCH GAUGE METAL-MINE LOCOMOTIVE

Hauling 40 cars, weighing 80 tons, over uniform "water level" grade in favor of loads. On account of the narrow gauge the motors are mounted high and connected to the axles through gears and side-rods. The battery is carried on a tender and the locomotive may secure power from the battery tender or from a trolley.

In this new field it is necessary, if best results are to be expected, to study the gathering cycle much more closely than is commonly done in recommending trolley gatherers. In the cases where the battery locomotives can safely be used, it is believed that the the mine operator will take care to promote his own welfare by providing proper charging facilities, inspection and careful operators. To get best results from a mule it must be watered, fed, shod, properly harnessed and worked within its capacity; battery requirements are different, but no more complicated, and must be attended to just as carefully.

Mine and industrial locomotives usually operate on narrow gauges and have limits of space and weight which prevent applying a battery of the capacity desired. While in a few cases conditions permit placing the battery on a separate tender, the self-contained unit has the advantage of smaller cost.

For out-door service, with wide gauge and ample space, as a rule, if the work is steady throughout the day, and over ten tons adhesive weight is required, more than one group of cells will be operated in parallel, and the first cost of the locomotive will usually be prohibitive. Exceptions to this are however, sometimes found. If the service is intermittent, such as switching, not requiring large kilowatt-hour capacity, yet requiring adhesive weight much above ten tons, batteries of the best types can be worked at high discharge rates, and reasonable priced locomotives used, such as shown in Figs. 8 and 9.

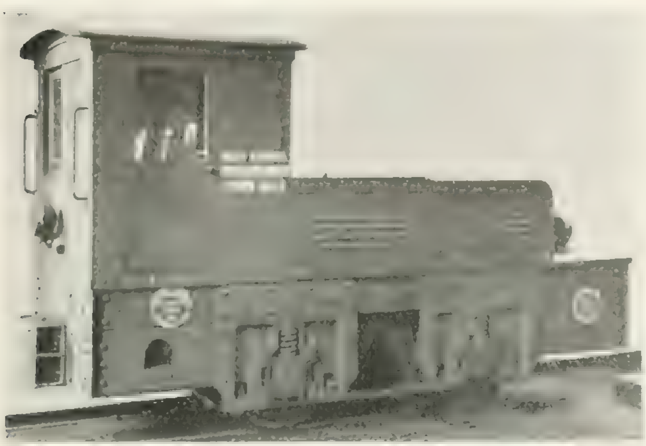

FIG. 6—A 5.5 TON INDUSTRIAL LOCOMOTIVE FOR OUT-DOOR YARD SERVICE AT A PULP AND PAPER MILL

Equipped with two 60 volt, divided field motors and series-parallel control. Gauge, 36 inches; battery, Edison A-8, capacity 300 ampere-hours.

FIG. 7—A SIX TON BAR-STEEL FRAME LOCOMOTIVE FOR A GOLD MINE IN ALASKA

Equipped with two 80 volt motors, each having the field winding divided in halves to obtain the full benefit of series-parallel control. Gauge, 26 inches; height, 48 inches; battery 68 cells, Edison A-10, capacity 375 ampere-hours.

With service fairly steady throughout the day, locomotives of from 2.5 to 10 tons offer in general the greatest possibilities of success. Standard locomotives are offered in these weights; the smaller sizes for a minimum of as low as 18 and 24 inch gauges. The number of cells is selected to charge from the available voltage but preferably from standard 110 or 125 volt circuits, because this permits efficient charging and discharging with 60 or 80 volt motors (depending on the battery). Motors are built with fields divided in halves, giving full advantage of series-parallel control which, with two motors, gives three controller notches without resistance in circuit. Over-motoring is avoided, to economize as much as possible in battery current. The batteries are conveniently placed on top and this fact means that the overall height is in standard designs from 46 to 48 inches above the rail. The motors are suspended so that the commmutators may be inspected without removing the battery. With two varieties of rugged cells available, designed for severe service and long life, it seems that the benefits of storage battery locomotives, will be extended to the cases where less desirable haulage systems are tolerated, as rapidly as these benefits are proven to be realities. Mis-application need not be feared if the particular conditions are carefully studied.

FIG. 8—A 15 TON INDUSTRIAL TYPE SWITCHING LOCOMOTIVE IN INTERMITTENT SERVICE

Handling lumber cars, etc., about the yards of the Victor Talking Machine Company. Equipped with two 60 volt, divided-field motors, series-parallel control, and air brakes. Gauge, 56.5 inches; battery consists of 120 cells of Edison A-8, operated in two parallel groups of 60 cells each having a combined ampere-hour capacity of 600.

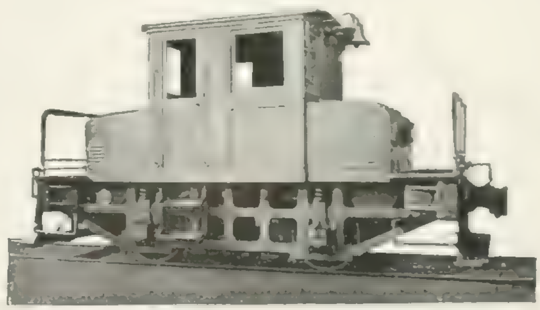

FIG. 9—A 25 TON BAR-STEEL FRAME, INDUSTRIAL SWITCHING LOCOMOTIVE USED BY A CENTRAL STATION

The service is intermittent and requires only small kilowatt-hour battery capacity, but large ampere discharge for short periods when handling the maximum load, which is hauling a standard railway coal car, weighing 75 tons, up a short three percent grade to the power plant. The battery consists of 48 cells, MV-19, Iron-Clad Exide.

Steel-Mill Motor Control

W. O. Lum

IN STEEL mills the application of electric motors extends from the driving of blowers, requiring little power and a simple starter, to the operation of the main rolls on blooming mills where the power demand reaches 10 000 to 15 000 horse-power or more, and where the controlling device is necessarily complex.

The solution of a very large proportion of the problems involved in applying motor drive to steel mill machinery lies in the controlling devices. In these times of safety, speed and efficiency, automatic devices are coming into use more and more, and it is, therefore, the purpose of this paper to deal more particularly with automatic or semi-automatic controllers. A brief outline of some of the more common methods of modern control for various mill uses will give a fair idea of the problems that are to be met.

Plain Non-Reversing Self-Starters are now reduced to a point of extreme simplicity by the use of contactors which have their operating coils in series with the motor. These series contactors have their magnetic circuits so arranged that a sudden rush of current through the winding will hold the contactor open. By means of an adjustment the contactor can be set to close when the current falls to the value desired. Thus the series contactor will accelerate a motor by the current limit method without the use of auxiliary devices of any kind. This type of contactor, because of its extreme simplicity, appeals very strongly to the steel mill engineer, although at first some errors were made in its application.

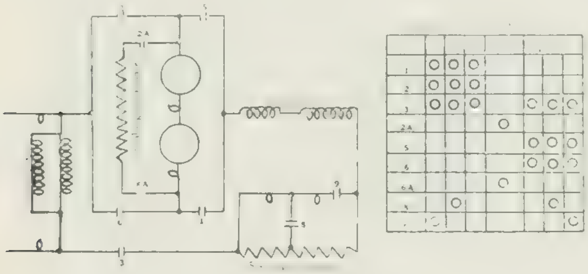

FIG. 1—DYNAMIC BRAKING SCREW-DOWN MOTOR CONTROL

The ability of a series contactor to remain closed is dependent upon the motor current, and therefore in all cases of regenerative loads it is necessary to provide a separately excited winding for holding the last accelerating contactor closed. Another limitation is that the series contactor does not lend itself at all satisfactorily to control systems where speed control by armature series resistance is necessary. In such cases it is not satisfactory even when used as a relay for operating shunt wound contactors. The load fluctuations are liable to allow the relays to drop open, or, if this be provided against by the use of interlocking contacts, then, while running at a given speed, the next higher speed is only possible if the motor current is at a value sufficient to operate the series relay. A satisfactory system of control for this class of service is obtained by the use of individual series relays, operating shunt contactors. Such relays are held in the open position by current and in the closed position by gravity, and as a matter of safety they are better when mechanically interlocked with the contactors, each contactor operating the relay for the next succeeding contactor. Such a system is probably a little more costly than some others, but the absence of intricate wiring and electrical interlocks will probably outweigh this by a saving in upkeep and delays.

Aside from hoisting motors, some of the earliest motor applications in steel mills were made upon roll-tables. Some trouble was at first experienced with the motors themselves, but by far the greater amount of trouble was found in the controllers. It is probably a fact that the early controllers themselves, both manual and automatic type, were responsible for a great amount of trouble that the motor was blamed for. Today, motors and controllers equally well designed are available for handling this class of work.

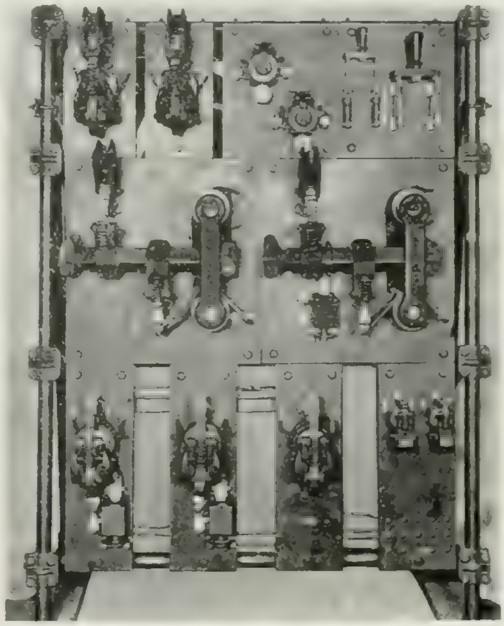

FIG. 2—CRANE HOIST CONTROLLER

Showing double-throw contactors and mechanically interlocked accelerating relay.

After motors were successfully applied to roll-tables they were tried for operating the screw-down on two-high blooming mills. Various types of control have been tried and abandoned and tried again for this service. A combination of very severe service with extreme accuracy and speed required a controller of quite a different sort than the usual plugging or dynamic-braking controllers. There are now available for this work dynamic-braking controllers which are

all that can be desired from the standpoint of accuracy, speed and endurance. The use of double throw contactors for making the reversing and braking connection has been the greatest factor in the successful solution of this problem.

Cranes and other unbalanced hoists are best handled by series motors, since the advent of methods for operating in the lowering direction with shunt motor characteristics. Controllers for operating series motors with the armature and field in series in one direction and in multiple when running in the opposite direction have been reduced to a remarkably simple form and give satisfactory results in all kinds of crane service.

Balanced hoists, such as furnace skips; require compound wound motors with controllers that will

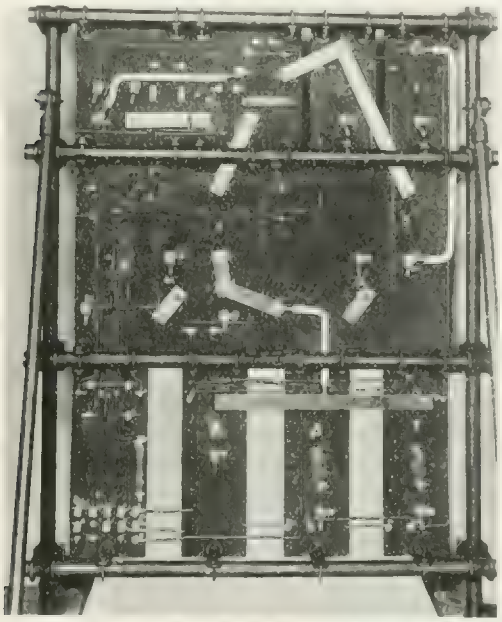

FIG. 3—WIRING OF CRANE HOIST CONTROLLER

give the necessary amount of slow down at the end of each trip. This slow down must be so arranged that the stop will always occur at the same point irrespective of the load that is being moved. Every precaution to avoid overtravel is necessary on hoists of this character and for this purpose the double throw contactor again lends itself admirably for the slow-down points.

Lift tables for three-high blooming mills require controllers similar to skip-hoists but without the variable slow down feature.

The adoption of motors for driving two-high, reversing blooming mills has made necessary an entirely different method of control because of the very high current values that obtain in the armature circuit. In order to reduce peak current demands upon the power house a fly-wheel motor-generator set is usually provided for furnishing power to the motor driving the mill rolls. The armature of the generator and the mill-motor are permanently connected by bus-bars and the control is effected by varying the generator field strength to the point of maximum generator voltage and by varying the motor field [illegible] speed. The motor is reversed by reversing the generator field. Current-limit control is possible throughout the entire range of acceleration by the addition of two series relays. In order to prevent creeping of the motor due to residual magnetism in the generator fields, the controlling device is arranged to connect the generator field and armature together in the off position, so that the armature potential will kill the field flux. The motor of the motor-generator set is provided with an automatic slip regulator so that peak loads are carried by the flywheel. This slip regulator is ordinarily a simple torque-motor, operating the plates of a liquid rheostat. Equipments of this type are giving excellent results in service.

Safety is a prime consideration in all steel mill apparatus. The term in this case not only applies to the operators and workmen but to the apparatus itself,

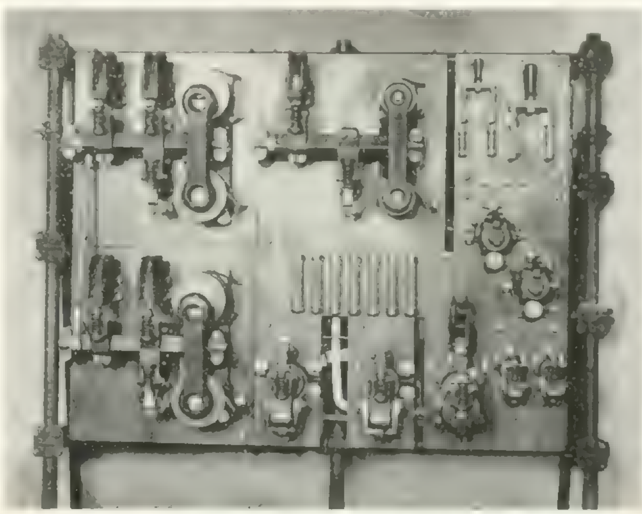

FIG. 4—CONTACTORS FOR LIFT TABLE MOTORS
On a three-high blooming mill

and some simple rules for the protection of men and apparatus may not be amiss.

1—All remotely controlled motors should be [illegible] some device at the controller that not only prevents the starting of the motor when the controller is locked, but also protects the workman from being shocked by the application of current to the motor.

2—All controllers operating machines where failure to stop is dangerous, either to the operator or the machine, should be arranged to disconnect the motor from both sides of the line when the controller is in the off position; and where magnetic controllers are used, the operator should have means for disconnecting both sides of the control circuit from the line. Screw-downs, skip-hoists, lift-tables, etc., are ordinarily operating so near the limit of travel that this feature of safety is only possible by arranging the master controller to open both sides of the control circuit lines.

3—Overload and no-voltage protection should be so arranged that it is necessary to return the master controller to the off position before a start is possible after a shut-down from either overload or voltage failure.

4—The enclosing cases of all master controllers should be grounded.

5—Hoisting controllers should be arranged so that failure of line voltage will not prevent stopping the motor.

Some of the special devices that have been developed for various purposes may be briefly explained as follows:—

The Double-Throw Contactor, mentioned in an-

other paragraph, has three points of advantage over other methods of obtaining the same results:—a—Positive interlocking is assured between the line contacts and the brake contacts; b—by means of a magnet in series with the brake contact, the motor must first come to a stop before it can be started in the reverse direction; c—the minimum amount of time is lost between opening the line and closing the brake circuit. This is all accomplished with out the use of interlocking contacts or other auxiliaries, and as the contactor is closed in the braking position by gravity, failure of

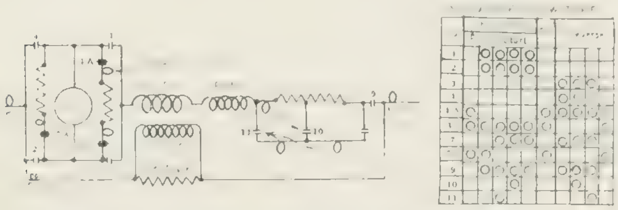

FIG. 5—BLOOMING MILL LIFT-TABLE MOTOR CONTROL

the control circuit means only that a slow-down or stop will occur as the case may be. Referring to Figs. 1 and 5 the method of applying double-throw contactors will be seen. The advantage of this contactor is particularly clear in the case of crane-hoist controllers.

The Mechanically Interlocked Accelerating Relay, shown in Fig. 2, is another device for simplifying the wiring and mechanism of automatic controllers. This relay is designed so that a spring holds it normally in the open position. The cap of the relay is so located under a contactor that when the contactor closes the cap is depressed. This releases the spring and leaves the relay plunger free to fall when the current in the operating coil falls to the value for which the relay is adjusted. The method of connecting these relays in the circuit is shown very clearly in the diagrams of speed controllers. The points to be borne in mind in designing such a relay are ruggedness and simplicity. Provision must also be made so that mill dust collecting on the relay will not interfere with its operation.

FIG. 6—SAFETY LOCK AND KEY FOR KNIFE SWITCH

Referring to Fig. 7 for automatic control of wound-rotor alternating - current motors, it will be noticed that the same sort of mechanically interlocked relay is used, as shown on direct-current controllers. The design of this relay presents some problems that are not present in the direct-current relay. Such a relay must operate on a frequency range from 60 cycles per scond to approximately one cycle per second without a very large percentage of variation in the drop-out point. By means of a correctly proportioned shading coil on the pole face of the relay, it is possible to secure operation at frequencies as low as one cycle per second without in any interfering with the operation at higher frequencies, and the difference between the operation on maximum and minimum frequency is very slight.

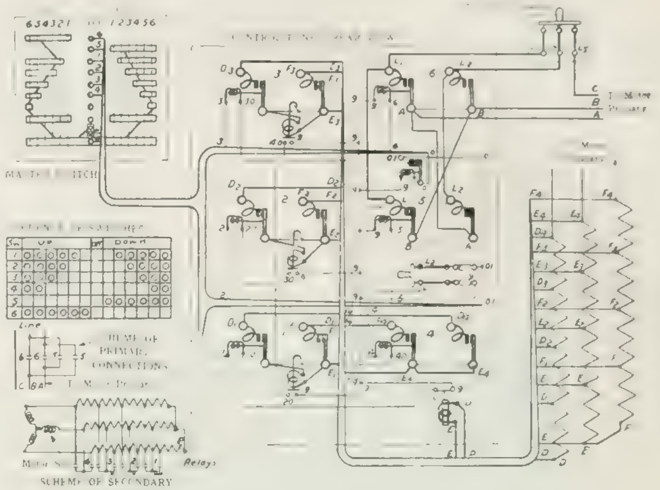

FIG. 7—DIAGRAM OF CONNECTIONS
For automatic-control alternating-current hoist service.

Overload Relays, provided with a magnet for resetting, become necessary in connection with remotely controlled motors in order to save time. Such relays are designed so that they catch in the open position when tripped out on overload. A magnet operated by a contact on the off position of the master controller releases this catch so that the relay falls to the normal position, ready for operation when the master controller is again moved to a running position. There are no special features about such a relay, other than that it must be extremely rugged in order to withstand the severe duty required in mill service, and the contacts must be so designed that vibration will not cause them to open the circuit.

FIG. 8—250 AMPERE SERIES-OPERATED DIRECT-CURRENT MAGNET SWITCH

The Series Contactor at first appears to be quite a complex piece of apparatus electrically. It is, however, quite simple. In Fig. 10, two magnetic circuits will be seen; one through the main air-gap, core, base, saturated-section, bearing and armature; the other through the main air-gap, core, base, hold-out air-gap, tail piece and armature. The operation is dependent upon the relative magnetic capacity of the saturated section and the other sections of the magnetic circuit. Magneto-motive-force applied at the core will drive flux across the main air-gap, through the armature,

and through the saturated section to the point of saturation. All flux in excess of this value will be forced across the hold-out gap. The area and length of the hold-out gap are considerably smaller than the area and length of the main gap, so that the density across

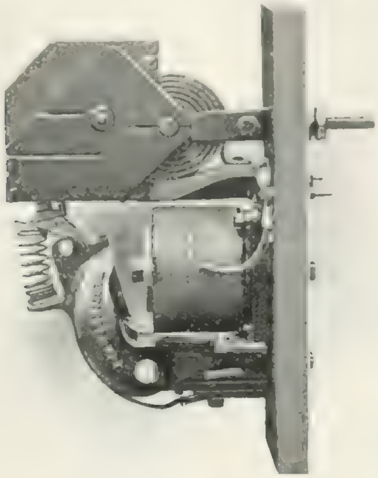

FIG. 9—250 AMPERE SHUNT OPERATED DIRECT-CURRENT MAGNET SWITCH

the hold-out gap is considerably higher than across the main gap. If all the flux in excess of that carried by the saturated section flows across the hold-out gap, at certain values the pull at this gap will be greater than the pull on the main gap, and therefore, the contactor will be held in the open position. Reducing the magneto-motive-force applied at the core, will reduce the lines across the hold-out gap and also across the main gap, but the rate of change at the hold-out gap

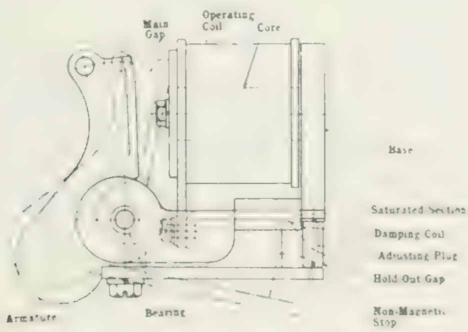

FIG. 10—DIAGRAM OF MAGNET FRAME

will be much greater than the rate of change at the main gap, as the hold-out gap is only getting a fraction of the total flux in the circuit; therefore, a point is soon reached where the pull at the main gap is greater than the pull at the hold-out gap and the contactor closes. In the calculation of such a magnet, it is only necessary to provide such a relation between the saturated section and the other parts of the magnet that this section is saturated at the minimum current at which the device must operate. In addition to the parts described, there must be some means provided for preventing the magnet from closing at the time the flux passes the pull-in point when building up. This may be accomplished either mechanically or electrically. The simpler method is electrically, and consists only in applying a short-circuited winding around

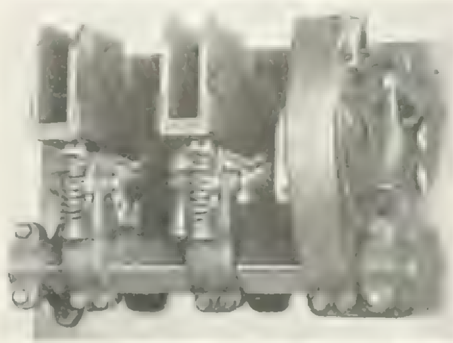

FIG. 11—DOUBLE-POLE ALTERNATING [illegible]

the saturated section so that when the magnet is first energized practically all the flux passes through the hold-out gap. This short-circuited winding on the saturated section serves also to make the contactor a little more positive in its operation, by holding it very firmly in the open position at the instant that the preceding contactor closes. It is usually the preceding contactor which energizes a series contactor, and, being adjacent, the shock would be sufficient to disturb

FIG. 12—DISMANTLED ALTERNATING-CURRENT CONTACTOR SHOWING ACCESSIBILITY

the operation of the series contactor were it not for the short-circuited winding.

In applying series contactors care must be exercised in laying out the starting resistance so that each step cut out gives the correct peak for operating the next contactor.

Electrically Operated Boot and Shoe Factories

C. N. Johnson

THE COLONY of shoemakers who settled near Boston established that industry in this country and formed the beginning of the largest shoe manufacturing center in the world. These early shoemakers cut out the parts of the shoes and distributed them to their neighbors, who made up the shoes, the women doing the light sewing and the men the heavier work. With the introduction of the first machinery, about the beginning of the last century, this "farming out" ceased and more centralized production began. The sewing machine has perhaps contributed as much as any one machine, toward the increase in production. At the time of the civil war, the increased demand for shoes, together with the shortage of labor, furnished a big incentive to the inventors of shoe making machinery. The first machines took care of the simpler operations and enabled them to be performed much more rapidly than by hand. The later machines are little short of human and work with amazing rapidity.

CLASSIFICATION OF SHOES

The different forms of shoes manufactured are the "machine or hand welt," the "McKay," the

TABLE I—RELATIVE PRODUCTION OF EACH TYPE OF SHOE MANUFACTURED IN THE UNITED STATES IN 1909

Type of Shoe	Number of pair manufactured	Percent of total output
McKay	107 063 000	43.2
Machine or hand welt	87 391 000	35.3
Turned	26 317 000	10.6
Wire screw or metal fastened	21 643 000	8.8
Wooden pegged	5 226 000	2.1

"turned," the "wire screw or metal fastened" and the "wooden pegged." Table I give a comparison of the number of pairs of each type manufactured, showing that the McKay and the welt shoe are the predominating styles. Of these, the turned and the welt are the most expensive classes of shoes.

The welt shoe may be distinguished by the fact that the sole is sewed completely through around the edge and derives its name from the fact that, after the upper part of the shoe has been sewed together and drawn over the forming last, a strip of leather known as the "welt," is laid along the lower edge of the upper on the last, beginning at the heel and extending around the toe back to the heel on the opposite side. This welt is sewed first to the insole and the upper, the stitching running around the edge of the insole and extending through the insole, the edge of the upper and the welt. The outsole is next cemented to this welt and the edge trimmed to the shape of the finished shoe. Then the shoe is taken to the stitching machine where a lock stitch is run around the edge of the sole, joining the outsole to the welt. In order that the stitching may not show on the insole inside the shoe or on the bottom of the outsole, a channeling machine turns up a lip from one quarter to one half inch wide around the edge of the sole. The stitching is then done through the remainder of the sole at the bottom of the groove thus formed, and the lip is cemented down over the stitching.

The McKay shoe differs from the welt shoe in that the stitching to hold the insole, upper and outsole together, is done from the inside of the shoe and runs completely through the insole, upper and outsole. This does away with the narrow strip of leather or welt between the bottom edge of the upper and the outsole, in the welt shoe. In making the McKay shoe the insole is fastened to the last and the lower edge of the upper pulled over it and tacked lightly. Then the outsole is placed over this and a few tacks driven through, enough to hold the form of the shoe. The last is then removed from the shoe and the shoe is taken to a McKay sewing machine which sews through the two soles and the upper. In this type

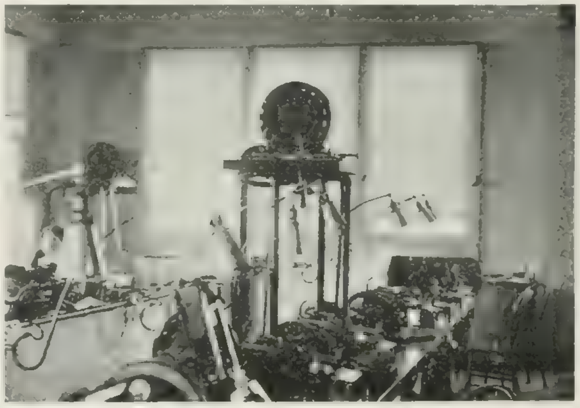

FIG. 1—A TWO HORSE POWER, 1 700 R.P.M. SQUIRREL-CAGE MOTOR BELTED TO SHAFT UNDERNEATH MACHINE BENCH IN SHOE FACTORY

of shoe also the outsole is usually channeled and the lip cemented down again after stitching, so that the stitching does not show on the bottom of the shoe.

The wooden pegged and wire screw fastened soles, have pegs or screws in place of the stitching in the McKay shoe. This means a cheaper construction and accordingly is used only in the lower grades of shoes.

The turned shoe is a woman's light shoe and, as the name indicates, is made up on the last inside out, and after attaching the sole to the lower edge of the upper, except for a small section of the heel, the shoe is removed from the last and turned right side out. In order to allow for this turning, the sole must be light and of very good material, while the remainder of the shoe is of an equally good grade of leather. This shoe has no insole, the lower part of the upper being stitched directly to the upper part

of the edge of the outsole, the stitching not extending through to the bottom of the sole. This is done by splitting the edge of the sole, inserting the edge of the upper in this opening, and sewing the upper to the top part of the split edge. After being turned right side out, this shoe must again be placed on a last, and the bottom of the shoe finished. To protect the foot from coming in contact with the stitching on the sole of the shoe, a lining of light high grade leather is placed in the bottom of the shoe.

FIG. 2—A GROUP OF TWO HORSE-POWER, 1 700 R.P.M. SQUIRREL-CAGE MOTORS DRIVING MACHINE BENCHES IN A SHOE FACTORY

THE HEEL

The attaching of the heel is practically the same operation in all types of shoes. The heel is built up of several layers of heavy leather. A machine known as a heel loading machine drives the attaching nails into that part of the heel which comes next to the upper, the nails projecting out enough so that a heel attaching machine forces these nails through the upper and the insole, clinching them against an iron plate on the bottom of the last. The row of nails or brads showing around the edge of the heel is driven in by a slugging machine, capable of driving about 350 brads per minute.

FIG. 3—A THREE HORSE-POWER, 1 700 R.P.M. SQUIRREL-CAGE MOTOR BELTED TO LINE SHAFTING DRIVING TWO SLUGGERS, TWO HEEL TRIMMERS AND A KNIFE-GRINDER

PROGRESS OF THE INDUSTRY

With the introduction of machinery to take the place of hand labor, beginning but little over a half century ago, the boot and shoe industry has made very rapid progress in this country. At the last census it ranked well up among the leaders, the value of its output being five hundred million dollars, or two and one-half percent of the total value of manufactures. Most of the foreign countries have been slow in adopting the latest form of labor-saving machines, with the result that this country is far in the lead. As machines have been added to supplant the old time shoemaker, both the quality at a given price and the quantity of shoes manufactured have risen. This increase in the application of machinery to shoemaking, as well as the increasing output, brought the power requirement of the industry in the United States in 1909 to approximately one hundred thousand horsepower. More than keeping pace with this growth during the past decade, electric motor drive has proven itself a valuable assistant to the boot and shoe manufacturer.

Massachusetts, the home of the shoe industry, is still far in the lead in the value of its output. Table II shows the distribution of plants, horse-power and output in five of the leading states. It will be noted that for Massachusetts the percentage of the total value of output is greater than the percentage of the total horse-power installed, which is due to the fact that a better grade of shoes and many hand made shoes are produced in this state, bringing the output per horse-power installed to a higher value.

TABLE II—DISTRIBUTION OF POWER USED IN THE BOOT AND SHOE INDUSTRY, INCLUDING CUT STOCK AND FINDINGS, ACCORDING TO 1909 CENSUS

	No. of Plants	Total Horse-power	[illegible]	[illegible] power	[illegible]	[illegible]
Massachusetts...	762	35 051	36.4	[illegible]	6 528	46.0
Missouri	58	11 [illegible]	[illegible]	[illegible]	[illegible]	9.5
New York	199	10 45[illegible]	[illegible]	2 963	2 168	9.4
Ohio	71	8 925	[illegible]	4 003	[illegible]	6.2
New Hampshire	66	8 582	[illegible]	[illegible]	926	[illegible]

ARRANGEMENT OF MACHINES

The large number of special machines operating intermittently and requiring but little power makes it very difficult to lay out the most efficient drive and grouping of machines for a large factory without a close study of the operations performed in each department. The modern shoe factory is usually a building of from three to five stories, covering a large amount of floor space. The operations are usually so grouped that the lighter parts of the shoe, the uppers and linings, are cut and assembled on the top floor. Another section prepares these parts and sews them together and they are then taken to the lasting room. Here the uppers and the parts of the sole are assembled and the shoe passed to the heavy stitching machine and to the sole forming machine. Here also the edge and bottom of the sole are finished, and the heel attached, and the shoe goes to the eyeleting

and button-attaching machines. It next receives the final finishing, blacking, polishing and marking, and is passed to the shipper.

POWER REQUIREMENTS

Since a large number of machines are required, scattered over a considerable area, the amount of belting and shafting to drive these machines from a single source of power is very large. By properly grouping the machines on individual motors, the majority of the heavy shafting and belting can be eliminated, thus doing away with a considerable amount of the friction load. It has been found advantageous to standardize on a small motor, usually a three or five horse-power, and to group the machines to furnish a load for this motor. In this way it is possible to arrange the grouping so that some of the motors may be shut down when the plant is not operating at full capacity. The load factor of this industry, or the ratio between the power used and the capacity of motors installed, over the operating period, which is usually nine to ten hours per day, ranges from 30 to 50 percent.

Steam is not required in any of the manufacturing operations and this, in connection, with the low power demand makes the use of central station power attractive to the manufacturer. With central station service, any department may be operated overtime on a rush job with but very little extra power cost. The adoption of central station service, allows the manufacturer to do away with the dirt and smoke attendant on the generation of power, and relieves the management from the overseeing of the power plant, which work is in no way related to the manufacture of shoes.

Table III shows the relative amounts of the different forms of power used, and the rapid advance being made in the use of electric power. In this table it is interesting to note that in 1909, electric motors formed 33.6 percent of the total power installed and 53.7 percent of the electrical horse-power was supplied from central station lines. This was an increase in use of central station power over 1899 of 355 percent.

TABLE III AMOUNT AND INCREASE OF EACH FORM OF POWER USED IN THE MANUFACTURE OF BOOTS AND SHOES, INCLUDING CUT STOCK AND FINDINGS

Year	Ave. Hp per Establishment	Horse-power Installed						Percent Increase over Five Years Previous					
		Total	Steam	Water	Gas	Electric Central Station	Electric Total	Total Power	Steam	Water	Gas	Central Station	Electric Total
1899	34	55 849	38 621	2 663	10 382	3 823	5 525	....	....	....	....	....	....
1904	42	63 968	44 387	2 270	11 352	5 959	12 663	14.5	14.9	14.7	9.3	56	129.0
1909	59	96 302	60 772	2 815	15 334	17 381	32 381	50.6	37.0	24.0	35.2	192	156.0

TABLE IV—POWER CONSUMPTION OF PLANT OUTLINED IN TABLE V

Power Consumption

1911		1912	
Month	Kw Hr	Month	Kw-Hr.
July	10 890	Jan.	17 700
Aug.	19 200	Feb.	19 200
Sept.	17 800	Mar.	18 200
Oct.	20 900	Apr.	20 300
Nov.	19 700	May	18 800
Dec.	16 800	June	19 100

The plant whose motor layout is given in Table V manufacturers largely McKay shoes of medium and low grade, for men, women and children. The factory was working at full capacity during the year for which power readings are given in Table IV, producing an average of 7 200 pairs of shoes per day. There are five hundred men and women employed working ten hours per day. An aggregate of 249 horse-power in 440 volt, three-phase, 60 cycle, induction motors is installed, all motors being of the squirrel cage type except the wound rotor motor driving the pump.

In this plant the electrical energy consumption per 100 pairs of shoes manufactured is 10 kw-hrs. which is below the average, due to continuous operation at maximum output.

TABLE V—A TYPICAL PLANT LAYOUT

No. of motors.	Hp.	R p.m.	Application.
			THIRD FLOOR
1	5	1700	Belted to a 50-ft. shaft (seven hangers). Connected load:—Eight United Shoe Machinery Co. Ideal clicking machines.
1	5	1700	Belted to a 30-ft. shaft (five hangers). Connected load:—Four Ideal clicking machines.
4	5	1700	Each belted to a 50-ft. shaft (seven hangers. Connected load:—Six Ideal clicking machines.
1	5	1700	Belted to a 70-ft. shaft (20 hangers). Connected load:—Twenty-two Union Special sewing machines, two Booth power folders, one Lufkin's Improved machine for folding shoe vamps and quarters, one U. S. M. C. sciver, one Knight perforator, two Amazon upper trimmers, one Fortuna upper trimmer, one Boston Machine Works upper trimmer,
1	3	1140	Belted to a 25-ft. shaft (nine hangers). Connected load:—Seven Union Special sewing machines, four Singer sewing machines, two lining markers, three economy cementing machines.
1	2	1700	Belted to a 20-ft. shaft (eight hangers). Connected load:—Seven Union Special sewing machines, two Wheeler & Wilson sewing machines, one Singer sewing machine.
1	2	1700	Belted to a 20-ft. shaft (eight hangers). Connnected load:—Six Wheeler & Wilson sewing machines, two Singer sewing machines.
1	5	1700	Belted to a 40-ft. shaft (ten hangers) Connected load:—Twenty Union Special sewing machines, fourteen Singer sewing machines, two Columbia beaders.
1	5	1700	Belted to a 40-ft. shaft (ten hangers). Connected load:—Seventeen Singer sewing machines, nine Union Special sewing machines, three Columbia beaders, one Reece button attaching machine.
1	5	1700	Belted to a 40 ft. shaft (ten hangers). Connected load:—Twenty-five Union Special sewing machines, five Singer sewing machines, four Singer special stitching machines, two Singer button attaching machines.
1	5	1700	Belted to a 70-ft. shaft (15 hangers). Connected load:—Six Reece button attaching machines, twenty buttonhole machines, seventeen Columbia beaders, two Emory cementing machines.

1	5	1700	[illegible] Block, Heel & Seat Co. [illegible]
			SECOND FLOOR
1	5	1700	[illegible] U. S. M. Co. [illegible] U. S. M. Co. [illegible]
1	5	1700	Belted to a [illegible] model [illegible]
1	5	1700	Belted to a [illegible] U. S. M. Co. [illegible] U. S. M. Co. [illegible] U. S. M. Co. [illegible] chine.
1	5	1700	Belted to a [illegible]-ft. shaft (three hangers). Connected load:—[illegible] cutting machine, one [illegible]-ft. beam outsole cutting machine.
1	5	1700	Belted to a [illegible]-ft. shaft (three hangers) [illegible] insole cutting machines, one Summit splitting machine, one Victor rolling machine, model E.
1	5	1700	Belted to an [illegible]-ft. shaft (three hangers). Connected load:—[illegible] chines, pulley 18 in. diam., rim 4½ in. x 2 [illegible]
1	5	1700	Belted to a [illegible]-ft. shaft (three hangers). Connected [illegible] outsole cutting machine.
1	5	1700	Belted to a [illegible]-ft. shaft (three hangers). Connected [illegible] McKay [illegible] one U. S. M. Co. channel cutter, one 6-in. [illegible]
1	5	1700	Belted to a 15-ft. shaft (three hangers). Connected load:—Two McKay heel loading and attaching machines, one U. S. M. Co. new loose nailing machine.
2	5	1700	Each belted to a [illegible]-ft. shaft (three hangers). Connected load:—[illegible] heel [illegible]
1	5	1700	Belted to an 8-ft shaft (two hangers). Connected load:—Two McKay heel loading and attaching machines.
1	5	1700	Belted to a [illegible]-ft. shaft (six hangers). Connected load:—Eight [illegible] pulling-over machines.
1	5	1700	Belted to a 25-ft. shaft (five hangers). Connected load:—Three Rex pulling-over machines, six Consolidated lasting machines, three U. S. M. Co. sole tackers.
1	5	1700	Belted to an 80-ft. shaft (nine hangers). Connected load:—Four Rex pulling-over machines, eight Consolidated lasting machines, four U. S. M. Co. sole tackers.
1	5	1700	Belted to a 60-ft. shaft (eight hangers). Connected load:—Four U. S. M. Co. double head, taper nail tacking machines, two U. S. M. Co. new loose nailing machines, one six-inch emery wheel, one sole polisher and finisher, one 8-in x 2½ in. double emery wheel, four insole cementers.
1	5	1700	Belted to a 50-ft. shaft (seven hangers). Connected load:—Eight Richardson [illegible] stitchers.
1	5	1700	Belted to a 30-ft. shaft (six hangers). Connected load:—Three Regent [illegible] ing wheels.
1	5	1700	Belted to a 40-ft. shaft (seven hangers). Connected load:—Four U. S. M. Co. sole finishing machines, two double sole turning machines., four double polishing wheels.
1	5	1700	Belted to a 40-ft. shaft (seven hangers). Connected load:—Five U. S. M. Co. [illegible] heel burnishers, two heel grinders.
1	5	1700	Belted to a 40-ft. shaft (seven hangers). Connected load:—Ten sole and heel burnishers.
1	5	1700	Belted to a 35-ft. shaft (five hangers). Connected load:—Seven U. S. M. Co. edge trimmers.
1	5	1700	Belted to a 30-ft. shaft (five hangers). Connected load:—Two U. S. M. Co. edge trimmers, five U. S. M. Co. double heel scouring machines, model R.
1	5	1700	Belted to an 18-ft. shaft (three hangers) and an 18-ft. countershaft (three hangers). Connected load:—Four Universal slugging machines, three McKay rotary heel turning and [illegible] model B, one imperial grinding machine, model H.
1	1	1700	Belted to ½-kw, 110-volt, direct-current generator used to operate call-bell system.
			FIRST FLOOR
1	1	1700	Belted to a 20-ft. shaft (three hangers). Connected load:—Four double buffing wheels.
1	5	1700	Belted to a 30-ft. shaft (five hangers). Connected load:—Three pasteboard box sealing machines, three pasteboard cover sealing machines
2	½	1700	Each geared to Mattison Mach. Co. embossing and stamping machine.
1	½	1700	Belted to a small bench lathe.
1	5	1700	Belted to a 20-ft. shaft (four hangers). Connected load:—Two Parson's 4-ft. beam lining cutters.
1	7½	1740	Geared to a Westinghouse Mfg. Co. 5-in. x 7-in. plunger pump, 50 strokes per minute.
1	10	675	Direct connected to a B. F. Sturtevant Co. No. 50 slow-speed, low-power exhaust fan.
1	15	565	Direct connected to a B. F. Sturtevant Co. No. 00 slow-speed, low-power exhaust fan.
2	8	730	Each belted to the driving mechanism of an Edmonds 2-ton freight elevator.

Electric Drive in the Laundry

H. F. Boe

LAUNDRY PLANTS are admirably adaptable to electric motor drive and particularly to individual motor drive. In fact individual motor drive has shown a saving in power of from 35 to 50 percent over line shaft drive, in a number of tests made in plants in different parts of the country.

Individual Motor drive will eliminate line shafting and belts, reduce the friction load of the plant, permit the proper placing of individual machines to facilitate handling the work and assure cleanliness and light, all of which are very important items in a laundry. It will also reduce the danger of accident and allow a flexibility of operation not obtainable by line shaft drive even with the use of cone pulleys. The summation of these items means increased efficiency, i. e., decreased operating expenses.

Group Drive, generally speaking, is undesirable for the reason that the groups must contain machines which are not in constant use, thus increasing the operating expenses since it is necessary to have the shafting and belts running. However, group drive is a compromise between steam or gas engine drive and individual motor drive, it being better than either steam or gas engine drive, and not so good as individual motor drive.

MOTOR APPLICATIONS IN THE MODERN LAUNDRY

In introducing electric motor drive into the laundry field it must be borne in mind that the laundry requires, besides power, a large amount of steam for drying, water boiling, heating and supplying hot water. This at once brings up the question as to whether it is advisable to buy the electric energy from a central station and produce the steam at the plant, or produce steam and electric current on the premises. A careful study of local conditions must be made in order to determine the most economical way. However, as a rule central station power can be shown to

be more economical and reliable and is of particular advantage for emergencies and overtime work. Individual motor drive is recommended and the following data refers to this class unless otherwise stated:

Laundries may be divided into three general groups:—

1—Those doing family work only.
2—Those doing railroad or steamship work only.
3—Institution laundries or those doing hotel, hospital or club work.

The work done in a laundry may again be divided into three groups as follows:

1—Flat work.
2—Starched work.
3—Rough dry work.

The machines used in each case are; for "flat work," washers, extractors, dry-room tumblers, and flat work ironers; for "starched work," washers, extractors, starchers, dry-rooms, dampeners, ironers, and finishing machines; and for "rough dry work," washers, extractors and dry-rooms.

WASHING MACHINES

The washing machine used in a laundry consists of a stationary outside shell inside of which revolves

FIG. 1—TYPICAL LAUNDRY ROOM SHOWING METHOD OF LOCATING MOTORS

a cylinder. The goods to be washed are placed in this revolving cylinder and subjected to the agitation and action of the wash solution. To prevent tangling the articles being washed it is necessary that the revolving cylinder alternate its direction of rotation. This reversing action is accomplished in various ways:—

1—By the use of straight and crossed belts.
2—By the use of mechanical reversing devices, such as the "Clark gear."
3—By gearing a reversing motor to the revolving cylinder.

The general cycle of an average wash is as follows:—

1—Cold rinse, 10 minutes.
2—Cold suds and soda, 10 minutes.
3—Hot suds and soap, 20 minutes.
4—Bleach, 15 minutes.
5—Hot suds, 30 minutes.
6—Sour, 10 minutes.
7—Blue, 15 minutes.
8—Rinse, 10 minutes.

This will make a total of 120 minutes for the entire wash. This cycle, of course, will be varied in different laundries, and any decrease in the time required for the completed cycle will mean a corresponding reduction in the power consumed and hence in the cost of operation. One man can successfully operate four washing machines by taking them in rotation, as he can load and unload four of them in the time of a single washing and, in addition, give the necessary attention.

Washing machines using crossed belts for reversing are most economically driven by compound direct-current motors having commutating poles and by alternating-current motors of the squirrel-cage type, having high starting torque, in connection with a flywheel. However, on account of the extra cost of the flywheel, it is usually omitted, and the motors are required to take the peak loads. This method is open to the objection that, since the motors are usually mounted on top of the washer, the belts are necessarily very short and a high friction loss results due to the heavy belt tension.

On account of the acid fumes, steam and dampness, it has also been considered necessary to use enclosed motors in connection with this method of mounting, except when open motors are especially designed for it. The power required varies from 1.5 to 5 horse-power, depending upon the size of the washer, the usual speed being 1 800 r.p.m.

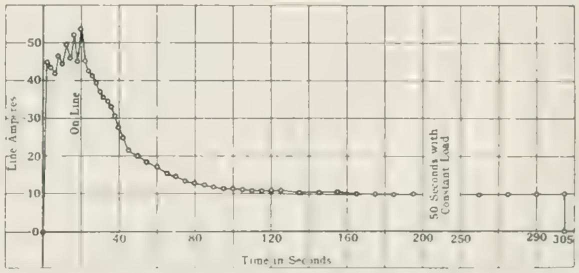

FIG. 2 AVERAGE CYCLE OF A 25-INCH EXTRACTOR DRIVEN BY A VERTICAL DIRECT-CURRENT MOTOR

The Clark gear method of reversing is considerably more costly than the crossed belt drive and is seldom used for individual drive, but is extensively used for group drive. The reversals are obtained by the use of clutches attached to two bevel gears which are driven by a third gear. These gears are timed to give the desired number of reversals per minute. The washer is so arranged that it has a shaft connection with either one or the other of the clutches. When used in group drive a number of washers are placed side by side and are driven from one shaft. The strain put upon the motor due to the reversals of one machine is counteracted by the flywheel effect of the other machines, since when properly arranged no two will reverse at the same time.

Direct-current motors for this service should be the standard compound-wound commutating-pole machine of the open type at any desirable speed. However, a speed of approximately 900 r.p.m. is used ordinarily in order that the motor may be geared directly to the counter-shaft. Squirrel cage induction motors having standard characteristics at 900 r.p.m. are suitable for this application. Three 36 by 70 inch washers require a 7.5 horse-power motor.

Reversing Motor Driven Washers.—The use of reversing motors is a comparatively new step in driving washing machines, but it has been tried out with very pronounced success and the indications are that it will be used to a much greater extent in the future if not adopted universally. These motors must be designed with special characteristics, cooling features and as little flywheel effect as possible. A heavily compounded commutating pole motor or a squirrel cage motor having high starting torque is used. The normal full load speed should be near 1 150 r.p.m. The motors are usually mounted on a bracket behind the machine and geared directly to it. The success of this application depends largely upon the timing element and control used since, if properly timed, the power will be cut off from the motor and the weight of the clothes will reverse the machine and start it in the opposite direction before the current is again applied, relieving the motor of the strain required to retard the cylinder and start it in the reverse direction. One and one-half to five horse-power motors are used depending on the size of the washer.

The control for direct-current motors should consist of clapper-type switches provided with magnetic blowout coils, and the reversing switches should be mechanically interlocked. A series relay switch should be provided to cut out the starting resistance when the predetermined current is reached, the motors being started through one step of resistance.

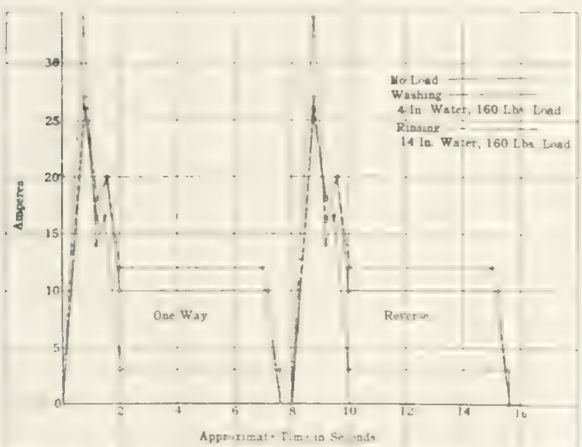

FIG. 3—TEST RESULTS OF A 30 BY 54-INCH TROY WASHING MACHINE

Alternating-current motors use the same type of control with the exception of the series relay, since they are connected directly to the line. Push-button stations are used and are usually inserted in the relay lines, carrying only a small current. Overload and no voltage release features are desirable.

EXTRACTORS

Extractors are machines employed to remove the water from the goods after washing. This is done by placing the pieces in a perforated basket which revolves at a very high speed, thus throwing the water out by centrifugal force. The peripheral speed of the basket must be kept within certain limits, depending upon the material and thickness of the basket wall. Copper baskets are most commonly used and are usually run at speeds from 6 500 to 7 500 feet per minute. When steel is used the peripheral speeds can be increased to approximately 9 000 feet per minute. The use of Monel metal allows a peripheral speed of approximately 9 500 feet per minute. The power required to start an extractor is very high, but after the basket comes to speed the power required drops rapidly to only a fraction of the normal motor rating.

There are various sizes of extractors, varying from 20 inches to 48 inches in diameter and requiring from one to 7.5 horse-power. The horse-power required at starting varies from two and one-half to three and one-third times the normal rating of the motor while the horse-power required at the end of the run varies from one-third to one-half. The time required to accelerate from rest to full speed is from 45 to 90 seconds. Fig. 2 shows the average cycle of a 25 inch extractor driven by a vertical direct-current motor, by a hand operated starting box.

The direct-current motors best adapted to this service are machines which have very heavy compound windings, with speeds on light loads that do not exceed the shaft speeds of the centrifugals. The lower the speed at starting the better, providing the motor has sufficient torque to accelerate the extractor in the desired time. Pulleys of approximately the same diameter should be used, if possible, upon motor and extractor. Alternating-current machines of the squirrel-cage type having high starting torque, and synchronous no-load speeds approximately the same as the shaft speeds of the extractors are most commonly used and give excellent results in service. Induction motors of the wound rotor type, having variable speed characteristics, would be more suitable to this application, but since this type of machine is more costly than the squirrel cage motor, and since the control would be more complicated and expensive, it is seldom if ever used on extractors in laundries.

The hand starters are being superseded by automatic starters consisting of clapper type magnetically operated switches controlled from push button stations. The direct-current controllers are equipped with series relays for starting, which automatically cut out the starting resistance when a predetermined current value is reached. The alternating-current controllers are equipped with series relays which cut out the auto-transformers when a predetermined value of current is reached. In some instances with small extractors, alternating-current motors are connected directly to the line.

Method of Drive—In most cases the motors are mounted on a bracket behind the extractor and are belted to the spindle pulley. Vertical as well as horizontal motors are used but vertical motors are not as satisfactory as horizontal, since the distance between belt centers is very short and the belts necessarily

have to be very tight, and bearing troubles usually result. In addition to the above, vertical motors require either top covers or drip shields, which interfere with the ventilation of the motor and add to the size and cost of the outfit. By using a horizontal motor and mounting it on a pedestal behind the extractor, and by using idler pulleys, greater distance between belt centers can be obtained, and an open motor with standard dimensions can be used.

STARCHERS

Starching machines are most commonly used for collar, cuff and shirt work.

The Collar and Cuff Starchers usually employ some method of soaking the goods in boiling starch, followed by pressure and a rubbing motion which exactly simulates hand rubbing. The goods are carried into the starch paste between open weave aprons and cannot become folded or wrinkled, but come out of the starch smooth and well filled.

There are several makes and types of these machines now on the market but the Hagan and Troy type machines are perhaps the most generally used and these machines require from one-quarter to three-quarter horse-power at any constant speed. These motors usually have covers or drip shields to prevent the entrance of spray starch and are of the constant speed non-reversing type. Various methods of mounting are used but the most common is to gear the motor to the machine by worm or spur gears.

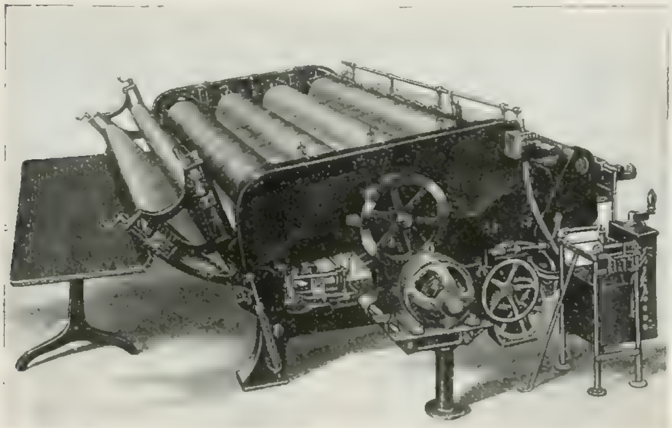

FIG. 4—LAUNDRY IRONER OPERATED BY A DIRECT-CURRENT MOTOR

Shirt Starchers—There are two common types of shirt starchers, one used for neck and waist band work and the other for shirt bosoming work. Both of these machines can be driven by horizontal motors of from one-quarter to one-half horse-power at approximately 850 r.p.m. In some cases the motors are belt driven while in others they are geared.

DRY ROOMS

There are two types of dry rooms, one which employs an endless chain conveyor system upon which the goods are carried through the room continuously and the other in which the goods are hung on racks or trucks and pushed into the cabinet.

The conveyor dry rooms are built in various sizes and depths and, besides operating the chains, the motor is required to operate one or more fans. The motor should never be mounted in the room proper as the temperature is very high. The best practice is to mount it on the wall or ceiling of the adjacent room and drive the regular countershaft of the cabinet by belt. The motors used for this service should be of the constant speed type and require from three-quarters to two horse-power at any speeds between 850 and 1 700 r.p.m., and should be equipped with some form of belt tightener.

The dry rooms employing the rack or truck method use a motor only to drive a fan for circulating the air. The fan requiring approximately a one-sixth horse-power motor is most commonly used.

Dry Room Tumblers—Dry room tumblers are used primarily for rough dry work and are built upon the same principle as the reversing washing machines. One or more fans are usually directly attached to the machine to blow or draw heated air over and through the goods to be dried. The motor is generally placed on the side of the machine and operates it by means of a silent chain connected to a countershaft from which the pulleys of the cylinder and the fan shafts are operated. The power required is from three to five horse-power at from 900 to 1 000 r.p.m. All direct-current motors should be compound wound and alternating-current motors should have high resistance squirrel-cage rotors.

Tumblers—Tumblers are used to loosen up flat work pieces which become entangled in the extractors. These machines are virtually the same as washing machines except that the cylinders are not encased and, of course, no liquids are used. The power required is from one and one-half to two horse-power, and any drive enumerated under the washing machine subject may be employed.

DAMPENERS

Dampeners are machines used to moisten all starched goods after drying and prior to the ironing process. The power required to drive these machines is from one-sixth to three-quarter horse-power. The motors require no special features.

IRONERS

Collar and Cuff Finishing Machines are usually small and are grouped together on a table and belted to a common shaft which is driven by a motor of from one-half to three-quarters horse-power. In some cases the motor is geared to the shaft while in others it is belted. This group usually contains a collar seam dampener, collar and cuff shaper, collar folder and a collar and cuff smooth edge ironer.

Steam heated collar and cuff ironers are usually individually driven by a constant speed motor, but they may be driven to advantage by a variable

speed motor, particularly where the steam pressure is apt to be low. Since the motors are small, three-quarter horse-power, there is no serious objection to using armature control for varying the speed. Collar and cuff ironers with gas heated rolls require constant speed motors of from one to two horse-power.

Bosom Ironers—Three distinct types of bosom ironers are in use: the reciprocating type where the bosom passes back and forth under a revolving drum; the one way type where the bosom travels in one

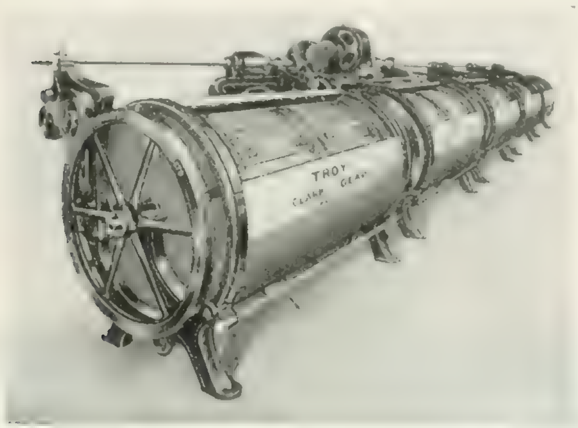

FIG. 5—A SET OF REVERSING WASHERS DRIVEN BY A SINGLE DIRECT CURRENT MOTOR

direction only under heated rolls; and the presses. Reciprocating ironers are built to reverse either mechanically or electrically. The mechanical reverse is obtained by gears actuated by a foot treadle. The electrical reverse is obtained by reversing the motor by means of a switch operated from a foot treadle. In both cases slow-speed motors of one-half horse-power capacity are used. The direct-current motors are shunt wound for mechanical reversing and compound for electrical reversing. The alternating-current motors are of the squirrel-cage type, with high resistance rotors for the electrical reversing machine. The one way machines require constant speed motors of one horse-power capacity. The presses require a motor-driven pump to compress a liquid (mostly oil) which in turn operates the press.

In some cases a reversing motor of one-half horse-power is used, while in other cases, non-reversing constant-speed motors of one-half horse-power are used.

Neck Band Ironers are similar to the sleeve and body ironer, except that they are smaller and require constant speed motors of from one-eighth to one-quarter horse-power.

Sleeve and Body Ironers—All modern sleeve and body ironers are of the reversing type, and are reversed either mechanically or electrically the same as the bosom ironers. The sleeve ironers require one-quarter horse-power motors and the body ironers one-half horse-power motors. Where reversing motors are used, the direct-current machines must be com- [illegible] versing is used, shunt wound direct-current motors, and low resistance squirrel-cage motors can be used.

Flat Work Ironers and Mangles—Perhaps no other machine in the laundry offers as many inducements to individual motor drive as the flat work ironer or mangle. It is necessary that these machines be placed where there is as little dust as possible and where good light is obtainable. Both the above features can readily be obtained by individual motor drive while it is practically impossible to do so with line shaft and belt drive. Variable speed motors should be used in order to be able to obtain the speeds necessary to do the best work on the various classes of goods to be ironed. The motors should be equipped with reversing controllers to facilitate re-padding of the rolls. Shunt-wound variable speed direct-current motors using field control and wound rotor alternating-current motors of the constant torque type give the best results.

These machines are built with and without aprons for carrying the goods and require from one-half to five horse-power. The smaller machines are usually made of the constant speed type, while the larger machines have from 2 : 1 to 4 : 1 speed range by armature and field control.

Dry Cleaning Plants—The motor applications for dry cleaning plants will be practically the same as for laundry work.

Every laundry man realizes the advantages to be gained by having his laundry clean, well lighted and properly ventilated. It not only creates cleanli-

FIG. 6—GENERAL VIEW OF A MOTOR-DRIVEN WASHER AND EXTRACTOR ROOM

ness and content among the employes, but increases their efficiency very materially, and makes it possible to run with the minimum loss of time in the hot summer months. Individual drive makes possible the use of improved ventilating systems and also increases their efficiency, since it eliminates practically all dust gathering and oil dripping caused by line shafting.

Fabrication of Rubber Goods.

E. C. Baugher

SCRAP RUBBER is extensively used in the manufacture of a wide variety of articles of daily use. But before it can be put to such use it must be reclaimed from the old rubber boots, shoes, hose, tires, etc., commonly known as scrap, by the rubber trade; also, a certain amount of pure gum must be prepared from the raw material for compounding with the reclaimed stock in the manufacture of rubber goods.

THE RECLAIMING PROCESS

When scrap is received at a reclaiming plant, it is first conveyed to a tumbler where the loose dirt is removed. From the tumbler it is emptied into mills called "crackers" which have two steel rolls, one corrugated and the other smooth, as shown in Figs. 1 and 2. Here the scrap is practically chewed up into small pieces, but is still far from being digested, for the stock put into tires, together with the fibrous

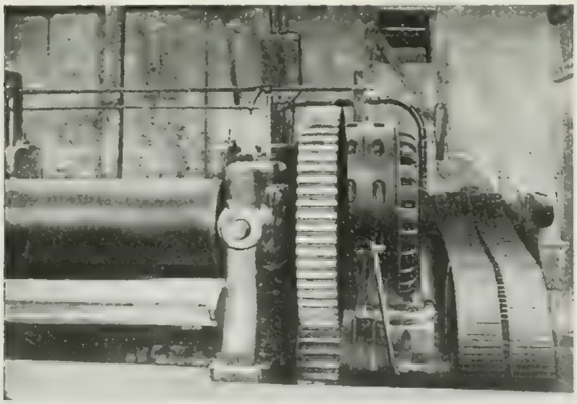

FIG. 1—MOTOR-DRIVEN MILL SHOWING DOUBLE MORSE CHAIN DRIVE AND HEAVY MILL GEARING

material, forms a substance which is not easily reduced to a condition in which it can be used to advantage again. So from the crackers the broken up scrap is taken to a sulphuric acid bath where it remains for about four hours, the fibre being entirely disposed of. From the acid bath the stock goes to a tub washer which consists of an elliptically shaped tub with a rotating paddle wheel on one side. Here the acid and other foreign matter are washed from the stock, usually requiring an hour or two. The stock then goes to a "devulcanizer," (this term is a misnomer, but still a name which clings to the trade), which consists of a large iron cylinder into which the stock is placed. The end is then closed, steam is admitted at a temperature of about 350 degrees F., and the stock is subjected to this temperature for from four to thirty-six hours. To explain "devulcanizing" it is necessary, first, to detail the process of vulcanizing, which consists in subjecting the stock, which has been compounded and mixed with sulphur in a mill called a "mixing machine," to a given temperature for a definite period of time, depending upon its quality and the use to which it will be put, in the same type of cylinder as used for devulcanizing. At the temperature used, some of the sulphur particles are converted into a vapor or gas and combined with a rubber compound. By this process the rubber is hardened, toughened, made durable and vitalized. In the devulcanizing process, a higher temperature is used, so that the sulphur is driven out of the compound, which is reduced to a plastic form, without elasticity.

From the devulcanizer, the stock enters an open dryer with a temperature of about 120 degrees F. After it has become thoroughly dried, it passes on to the grinders and sheeters where it is pulverized, mixed with various compounds and run out into sheets. This reclaimed stock is used in the manufacture of almost every kind of mechanical rubber goods on the market, but for the better grade of rubber

FIG. 2—VIEW OF RECLAIMING DEPARTMENT SHOWING MILL DRIVEN BY TWO 150 HORSE-POWER AND ONE 200 HORSE-POWER SQUIRREL-CAGE INDUCTION MOTORS OPERATING AT 435 R.P.M.

The mills are driven in three rows by line shafts beneath the floor.

goods, such as tires, a certain amount of pure gummed stock is mixed with the reclaimed stock in order to prolong its life and give it staying and wearing qualities.

TREATMENT OF PURE GUM

When pure gum is received in a rubber factory it is in the form of large bales or biscuits. These are first cut into pieces on a rapidly revolving circular knife with water running over it. In winter the gum is then put in a hot bath to remove all frost. It is then put through the crackers, the latest type of which has two chilled steel rolls, about 18 by 30 inches, grooved longitudinally with rectangular grooves, and geared together so as to give different peripheral speeds to the rolls. If this stock is pure para, it is then washed in a tub washer; pontianac and guayule are not usually put through washers. The stock then

passes to a sheeter, the latest type of which has two rolls 18 and 16 by 40 inches, grooved circumferentially, with four longitudinal grooves and geared together in the same manner as the crackers. Six of the sheeters can be fed by two crackers. From the sheeters pure para and pontianac are dried for about three weeks in a room having a temperature of about 90 degrees F.; guayule is dried in a steam heated dryer, requiring about three or four hours only, the latter gum not being injured by the rapid drying and high temperature.

From the dryers the gum goes to the drug room, where it is proportioned with various ingredients, depending upon the ultimate use for which it is intended, and then to the compound room, where it is mixed in mixing machines. After it is mixed, it is allowed to season for three or four days before being put into warmers, where the stock is heated for the calenders.

THE CALENDERING PROCESS

In the calender room one of the most important processes of the industry is carried on. The calender is used for three different purposes—"skim coating," "frictioning" and "calendering" or "sheeting" rubber. In the skim coating process, the stock is simply

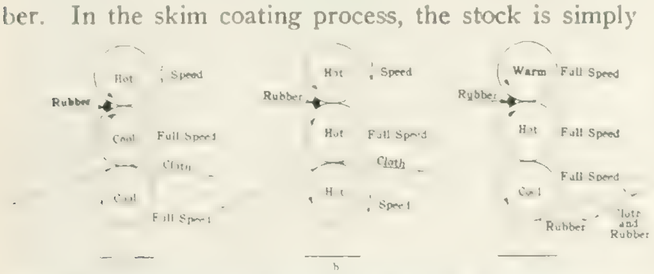

FIG. 3—A REPRESENTATION OF THE OPERATION OF A CALENDER IN VARIOUS RUBBER MAKING PROCESSES

a—Skim coating. b—Frictioning. c—Calendering.

spread over the surface of cloth in very much the same manner as that used in spreading machines in which carriage tops and automobile covers are prepared. In friction work the stock is rubbed into the fabric so that the cloth is entirely impregnated with the rubber compound. This stock is used for making automobile tires, rubber belts, etc. In calendering or sheeting rubber, the stock merely passes through the rolls and comes out in sheets of different widths, depending upon the number of knives used in cutting. This stock is used for inner tubes of automobile tires, rubber treads, etc.

A clearer impression of each of the above processes may be obtained from Fig. 3. In Fig. 3-*a* the calender rolls are shown prepared for the process of skim coating. The top roll is hot and is geared to operate at two-thirds the speed of the other two rolls, both of which are operated cold. The stock is fed in between the top and center rolls and clings to the center roll, but leaves it at the time of spreading on the fabric, which passes between the center and the bottom rolls. Usually five men are required for operating a calender during this process.

In Fig. 3-*b* are shown the three rolls of a calender prepared for friction work. In this case all three rolls are kept hot and the center roll operates at a much higher speed than the other two. The stock is fed in between the top and center rolls and clings to the center roll. The speed of the fabric as it passes between the center and bottom rolls is less than the peripheral speed of the center roll so that the stock is rubbed into the cloth and the latter is thoroughly impregnated. Usually three men are required to operate a calender for such work.

In Fig. 3-*c* are shown the rolls of the calender prepared for calendering rubber. All three rolls are geared to operate at the same speed, the top roll being warm, the center one hot and the bottom one cold. The stock is passed between the top and center rolls and clings to the center roll, so that in order to remove it in the form of a sheet when starting up, it is necessary to cut the stock longitudinally from the center roll and let it pass around under the bottom roll to the reels on the other side of the calender. Five men are required for calendering. The stock produced from a calender by this process is usually cut into strips by small knives pressing against the face of the center roll opposite the side upon which the stock is entered; these sheets of rubber are then wrapped around cloth in the process of winding up on the reel in order to keep the layers from sticking together.

POWER REQUIREMENTS FOR RECLAIMING STOCK

The power required for driving various machines in the rubber industry can be discussed only in a general way without the use of data from exhaustive tests which, without knowing the nature of the stock in each case, migh be very misleading. The following factors are involved in the study and use of motors for driving the various machines.

The Mill Drive has an extremely fluctuating load, the power required being governed by the size and speed of the rolls which are used, by the quality of the stock being broken down or mixed, by the temperature and the rate at which this stock is fed to the rolls.

Crackers vary considerably in size, but for crackers having about 16 by 36 inch rolls, such as described previously, used in breaking down scrap rubber, the power required for each machine averages about 25 horse-power. Where a large number of these are belted to one shaft, the load factor of this shaft must be taken into consideration so that in the case of ten crackers, for instance, a 200 horse-power motor would be of ample size.

The Grinders used in the reclaiming plant referred to above require only about 20 horse-power each for mills 15 by 45 inches. The stock being very soft, requires a correspondingly small amount of power. In one large reclaiming plant where there are installed 42 grinders of the above size, a 750 horse-

power motor was installed to drive the machines.

POWER REQUIREMENTS FOR PURE GUM

In a plant which handles largely pure gum stock, the power requirements are very different. For instance, in the case of the crackers and sheeters in the washing room, as noted above, two crackers will feed

FIG. 4—DETAIL VIEW OF MOTORS AND MORSE CHAIN DRIVES SHOWN IN THE BACKGROUND OF FIG. 2

six sheeters and for a line shaft to which mills of the above type are belted, an average of 25 horse-power per mill will be suitable. Of course, at the time of throwing large pieces of pure para into a cracker, the momentary horse-power is very great, but this drops off immediately after the stock is broken down.

Mill Drive—The power required for driving mills which are used for mixing rubber compounds will be governed by the size of the mills. The starting requirements are heavy, and large momentary peaks are common, so that a wound-secondary motor is desirable. Each specific case, however, must be

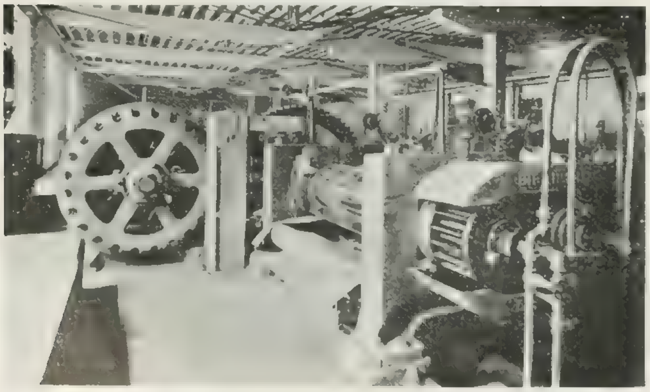

FIG. 5—A SQUIRREL-CAGE INDUCTION MOTOR DRIVING THREE 18 IN. BY 60 IN. MIXING MILLS, ONE OF WHICH IS SHOWN IN THE FOREGROUND

thoroughly investigated with respect to the quality of stock being used and the size and speed of the rolls. When driving a number of mills from one shaft by a motor, it is a good plan to have a large flywheel on the end of the shaft, which not only smooths out the peaks, but relieves the chain of gears from undue strains.

Calenders—It has been found that calendering or sheeting rubber requires more power than skim coating or friction work for a given speed. Frictioning is run at a higher speed than calendering, however, and consequently a larger motor is often required for frictioning than for sheeting. It has also been found

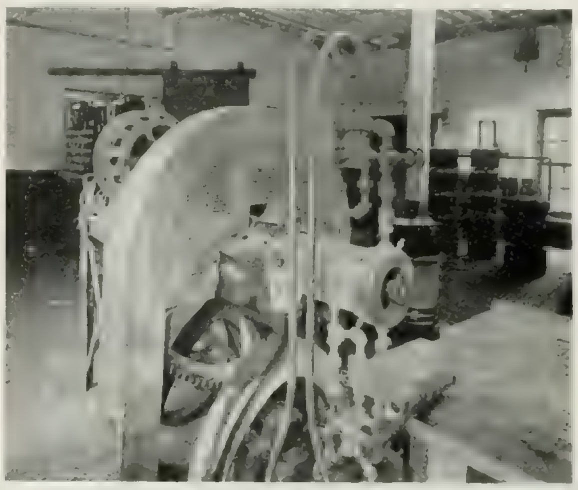

FIG. 6—A FOUR INCH TUBING MACHINE DRIVEN BY A SQUIRREL-CAGE INDUCTION MOTOR

that the power required for driving a calender increases as the distance between rolls decreases. This is especially marked where the stock is hard and is accounted for by the increased wedging action when the rolls are brought closer together. Calender drive is nearly a constant torque proposition, although the torque required is somewhat greater at speeds below ten yards per minute. This is shown by the fact that at constant torque the horse-power required should

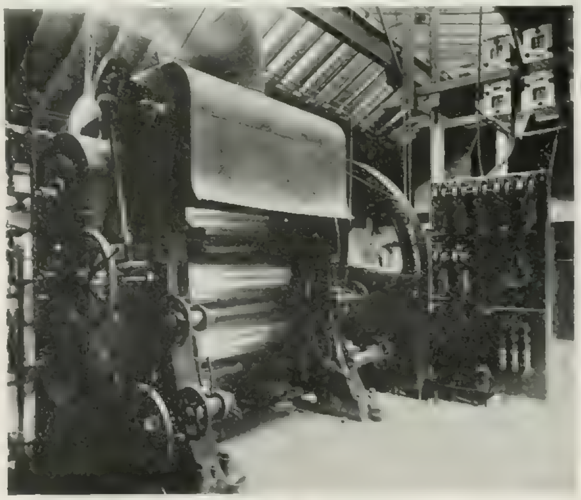

FIG. 7—A THREE ROLL, 22 IN. BY 66 IN. CALENDER DRIVEN BY A DIRECT CURRENT MOTOR WITH AUTOMATIC UNIT SWITCH CONTROL PANEL

drop off in proportion to the decreasing speeds, but at less than ten yards per minute the horse-power does not decrease in this proportion. It was recently found in one rubber mill that due to the nature of a certain kind of stock which is used in making rubber heels, the power required for driving the calender at the lower speeds was increased very

greatly, thus, instead of the torque remaining constant throughout the range of speeds, it was practically doubled at about ten yards per minute. It is, therefore, not safe to assume that the torque required to drive a calender will remain constant at all speeds.

SPEED CONTROL

Because even increments of speed can be secured with direct-current motors, as well as the advantage of dynamic braking in case of emergencies, this type

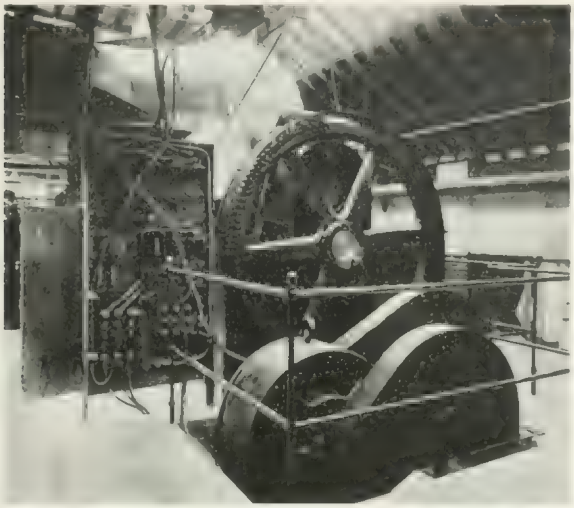

FIG. 8—DETAILS OF MOTOR AND CONTROL SHOWN IN FIG. 7

of motor is preferred by rubber mill superintendents for calender drives. A speed range of 300-900 r.p.m. can be secured by field control when back-geared motors are adopted, but this arrangement is not nearly so compact as that secured by a lower speed range. For instance, a motor having a speed range of 235 to

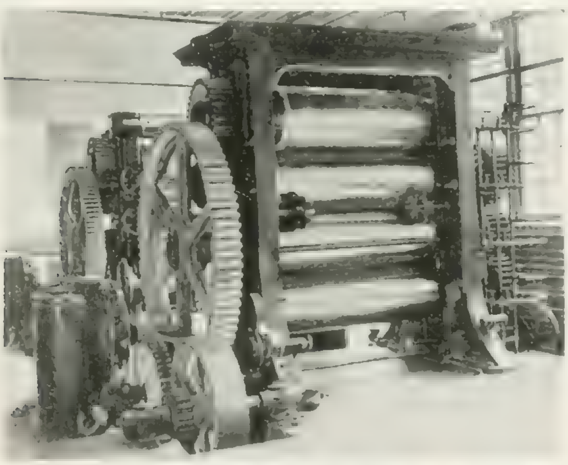

FIG. 9—A FOUR-ROLL CALENDER DRIVEN BY A SQUIRREL-CAGE INDUCTION MOTOR

Showing compact arrangement possible by the use of the Morse chain drive.

700 r.p.m. by field control, and lower speeds by armature control, can be connected by chain directly to a sprocket on the calender pinion shaft. Very frequently the motor can be located in the basement and no space whatever is required on the calender room floor for the motor.

The control panel should be of the magnet switch type operated from a master controller, which should [illegible] can be stamped numbers corresponding to yards per minute of production. If desired, the controller may be locked at any speed to prevent the operator speeding up near quitting time in order to finish a piece of material, or slowing down so that he can loaf on the job, either of which might impair the quality of the goods.

From careful records kept in one large rubber plant, it has been found that three electrically driven calenders will turn out the same amount of work as four which are mechanically driven from a line shaft; this is due to the wider range of speed secured through the ability to secure even increments of speed and the time saved in changing from one to another. In other words, each grade of stock can be run at the limiting speed, whereas a mechanically driven calender has but two speeds—a high and low—and if a

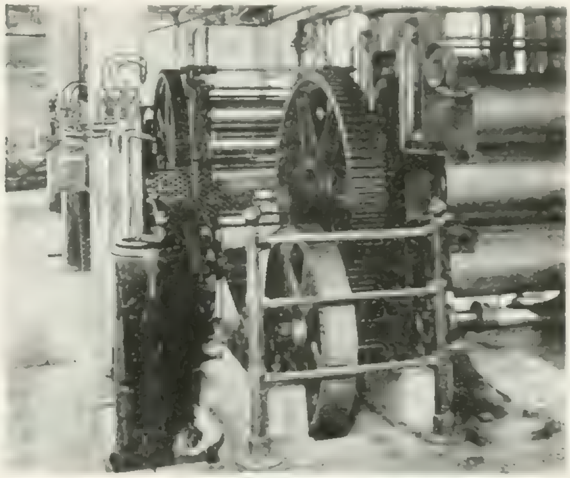

FIG. 10—A THREE-ROLL CALENDER DRIVEN BY A SQUIRREL-CAGE INDUCTION MOTOR

Showing Morse chain drive with single gear reduction as compared with the double gear reduction of Fig. 8.

given material will not stand the high speed but could be run faster than the low speed, this latter is its limit.

The fact that three electrically driven calenders will replace four mechanically driven has the following significance and should be taken advantage of:

The average three-roll calender costs installed........	$10 000
Fixed charges, e. g., interest, depreciation, insurance and taxes on this investment at 15 percent........	1 500
As each calender requires five men to operate it and these men are paid an average wage of $12 each per week, in one year wages saved..............	3 120
Assuming the average power required for a calender is 35 horse-power at thirty dollars per horse-power per year	1 050
Total	[illegible]
From this must be deducted the fixed charges incident to equipping three calenders electrically.	
3 calenders electrically equipped, including Morse chains	[illegible]
Interest, depreciation, insurance and taxes at 15 percent.	1 125
Net saving effected...........................	$4 545

or the cost of the electrical equipment will be returned in about 20 months.

Electric Drilling in the Oil Fields

W. R. Johnston

As usually found, petroleum consists of the hydro-carbons of a paraffin, asphalt and sulphur series, ranging from the heaviest oil to the lightest gas, the gas being held in a manner similar to carbonic gas in soda water. This combination of oil and gas is found in what is known as the oil sand, a porous layer which bends and dips much as any other strata, causing it to outcrop in some places, giving rise to oil seepage and in other cases going to unknown depths. To reach this sand it is usually necessary to drill through overlying, non-producing strata.

In general the drilling operations may be classified as cable drilling and rotary drilling, though quite frequently a combination of both methods may be used to advantage. In cable drilling a string of tools is alternately hurled upward and dropped onto the rock breaking it into small pieces. In rotary drilling the tool rests on the rock and cutting is accomplished by rotation. The parts which compose a string of tools used in cable drilling, and the variation in weight and length of those parts are shown in Figs. 1 and 2, together with the manner in which the string is fastened to the cable and suspended from the walking beam.

In cable drilling it is impossible to start drilling from the beam, because the drilling tools may be 28.5 to 63.5 feet in length while at a maximum the beam is not more than 18 feet above the derrick floor. In starting the well, then, it becomes necessary to do what is termed "spudding." The manner in which this is accomplished is best seen from Fig. 4. The pitman is disconnected from the bandwheel *B* and the drilling tools are suspended from the bull wheel *C*. A "jerk line" is attached to the wrist pin of the driving wheel *B*, and the other end of the line is connected with a "spudding shoe" which works freely on the cable. Rotation of the bandwheel gives a reciprocating motion to the tools. It has been found that for most efficient spudding the tools should be raised and dropped at a rate of approximately 40 to 50 times per minute. As the tools progress the operator gradually lets out the cable in accordance with the advance he is making. The depth to which he will "spudd" before putting the tools on the beam will depend on the weight of the tool and the strength of the derrick, since in this operation all the jar and strain passes through the derrick. When operating from the beam the strain is taken up by a substantial upright timber, the "sampson post," designed for this service.

When finally the strain has reached a point which makes it necessary to transfer these strains to the sampson post, the cable is caught up by a clamp hung from the temper screw as shown in Fig. 1, the pitman is fastened to the wrist-pin on the bandwheel and the motion of the bandwheel works the beam up and down, raising and dropping the tools. A good illustration of what takes place in drilling may be seen by taking a long elastic cord with a weight suspended from one end and moving the free end of the string up and down. For a definite length of elastic, the weight hits the ground with greatest force at a certain speed and to obtain a corresponding blow with increasing depth it is necessary to slow down the movement of the hand. The initial movement is also greatly amplified when it reaches the weight; we are told that in deep wells, with a three foot movement of the beam the tool is actually hurled upward nearly 15 feet. It is this hurling up of the tool, followed by an unrestrained or free fall, that gives rise to the most effective blow.

As the tools advance with repeated blows the temper screw is let out to keep the tool pounding on the rock. When the screw has traveled its length, 5.5 to 6 feet, the cable is released, the temper screw brought to its shortest length and the clamp put on higher up. This cycle is repeated throughout the drilling operation. In an average case the time taken in going this distance may vary from one-half to six hours, depending on the depth at which drilling is being done, and the nature of the formation. Where the bandwheel is run at 40 to 50 revolutions per minute in spudding its speed is reduced to 30 to 40 revolutions per minute when operating from the beam, and as greater depths are reached, is further cut down until at 3 000 feet the bandwheel will be running at only 18 or 20 revolutions. Where a steel cable is used instead of hemp, this speed may be as high as 20 or 25 revolutions per minute.

Variation from the proper speed, especially in deep wells, may be serious in that if the beam should pull up too quickly it might break the cable or on the other hand if the beam should fall out of synchronism with the motion of the tool, because it has slowed down, the tool would probably only travel through the distance traveled by the beam and would hang suspended above the rock. When such a condition exists the tool is commonly termed "dead."

The continued blows of the tool soon cause a lot of debris to accummulate, which, if permitted to remain, would impair the efficiency of drilling. To avoid this either of two methods may be employed. One is bailing and the other consists in washing away the material in what is known as a "hydraulic circulating system."

Preparatory to bailing the temper screw has to be removed from the drilling cable, the walking beam disconnected from the band wheel and the tool hauled from the well. Raising the tools is accomplished by driving the bull wheel from a rope passing

around a grooved pulley built upon one side of the band wheel. As the tools approach the surface, one man throws the driving rope off the bull wheel and another shuts down the motor. The tools are prevented from going back into the well by applying a hand brake to the bull wheel. The bailer is then lowered into the well by its own weight, the cable unwinding from what is known as the "sand reel," shown in Fig. 5. To prevent the bailer from accelerating to a dangerous speed, the sand reel pulley is pushed over into contact with a post brake. When the bailer reaches the bottom of the well and is filled, the reel is pulled over into contact with the face of the bandwheel, and the friction between the two raises the bailer to the surface.

FIG. 1

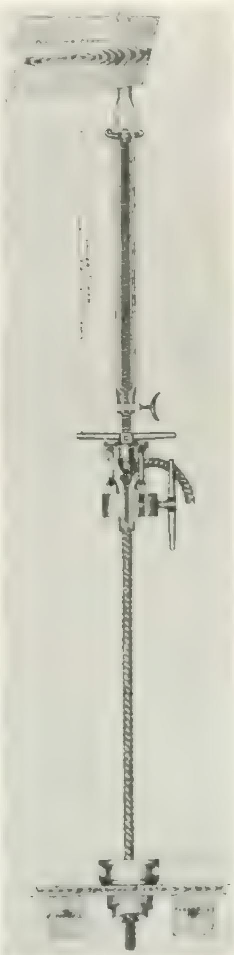

FIG. 2

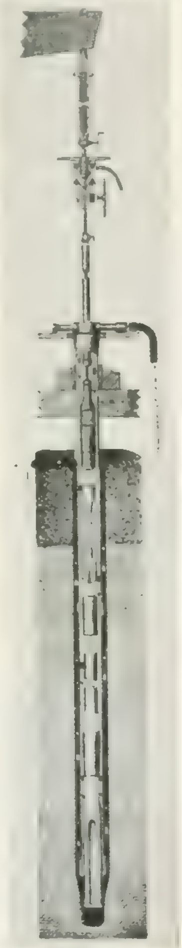

FIG. 3

FIG. 1—PARTS COMPOSING A STRING OF TOOLS FOR CABLE DRILLING

Rope socket—2.5 to 4 feet long, 100 to 125 lbs.; sinker—6 to 16 feet long, 120 to 1 500 lbs.; jars—about 5.5 feet long, 100 to 390 lbs.; auger stem—16 to 48 feet long, 300 to 4 700 lbs.; drilling bit—4.5 to 6 feet long, 100 to 3 700 lbs.

FIG 2—METHOD OF SUSPENDING STRING OF TOOLS SHOWN IN FIG. 1 FROM THE WALKING BEAM

FIG. 3—HYDRAULIC CIRCULATING DRILLING

The circulating water permits the casing to follow the drill more easily. This is especially adapted to great depths.

The bailer consists of a wrought iron pipe from 2.5 to 11 inches in diameter and from 17 to 30 feet in length. It is fitted with a bail at its upper end for suspension from the cable, and a flap valve at its lower end, carrying a dart, which protrudes through the lowest section of the pipe, so that on striking bottom the valve is forced up, permitting the inflow of the mixture. On raising the bailer the weight of the content closes the valve. Quite frequently the mixture is not sufficiently thin to flow into the bailer readily. To get a good load it is necessary to raise and drop the bailer through a height of five to ten feet, five or six times per minute, this action serving to stir up the water and get all the debris uniformly suspended. The bailing is continued until a clean surface is presented to the tool.

Usually contracts for drilling are placed at so much per foot and it is to the advantage of the operator to complete the well as soon as possible. In drilling he is limited to a speed best suited to the type and length of cable as well as to the nature of the formation he encounters. The only way in which he can cut down the time taken in completing the well is to increase the speeds at which he handles his tools, and bailer. The maximum rope speed he may select will depend upon the strength of his derrick, the power of his driving unit, and his ability to stop the tools between the derrick floor and top. A man is not warranted in building a derrick to withstand speeds higher than 500 feet per minute, for the number of times that these strains comes upon the derrick represent but a small part of its life and the difference in first cost would exceed in value the time saved. Installing a driving unit large enough to handle these peaks would mean very poor economy the greater part of the time when operating at the slower speeds. Practice would indicate that rope speeds of 275-312

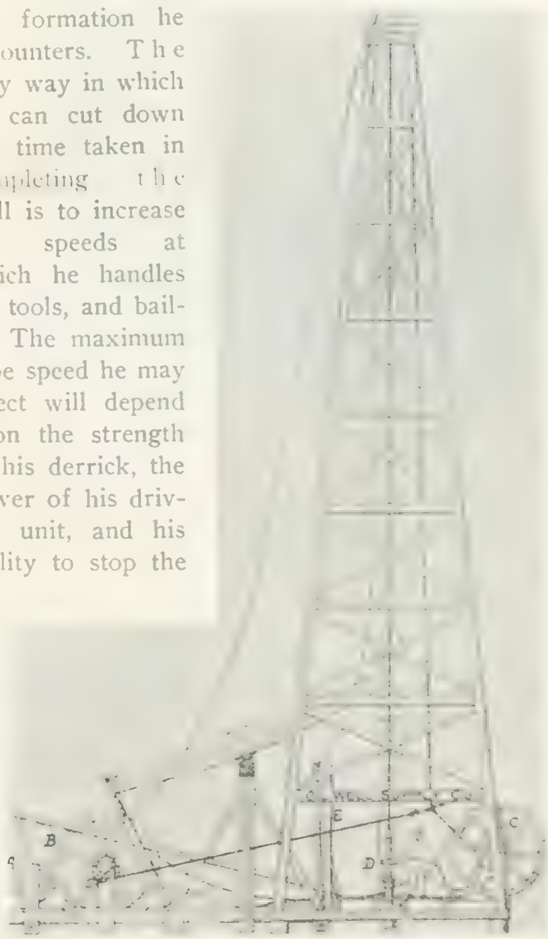

FIG. 4—DIAGRAM SHOWING THE APPARATUS USED IN CABLE DRILLING

A—Sand reel pulley. B—Band Wheel. C—Bull Wheel. D—Spudding clamp. E—Headache post.

feet per minute in hauling tools from the well and 200-400 feet per minute in raising the bailer are good averages. This means running the band wheel at approximately 30-75 r.p.m., different pulley ratios of the motor giving different rope speeds at the well.

In the hydraulic circulating system, drilling is accomplished by alternately raising and dropping a string of tools as in standard cable drilling. Instead of bailing, however, water is forced down the inside of the casing, passed under the shoe and returned to the surface carrying the drill cuttings to a sump, where they are permitted to settle out, after which the water is again circulated.

In standard cable drilling it is often necessary to drill through alluvial deposits and friable earth. To prevent the wall of the well from falling in onto the tools, a drive pipe is lowered with them until solid rock is reached, after which the tools drill ahead of the pipe. This pipe is a heavy wrought iron tube varying in diameter from three and one-half to twelve and three-quarter inches, and is fitted at its lower end with a forged steel ring, machined with an annular cutting edge to permit the pipe to sink more rapidly. Quite frequently the weight of the pipe alone is not sufficient to drive it down and it is necessary to use a drive clamp, actuated from the auger stem in such a way that raising and dropping the tools pounds the pipe into position.

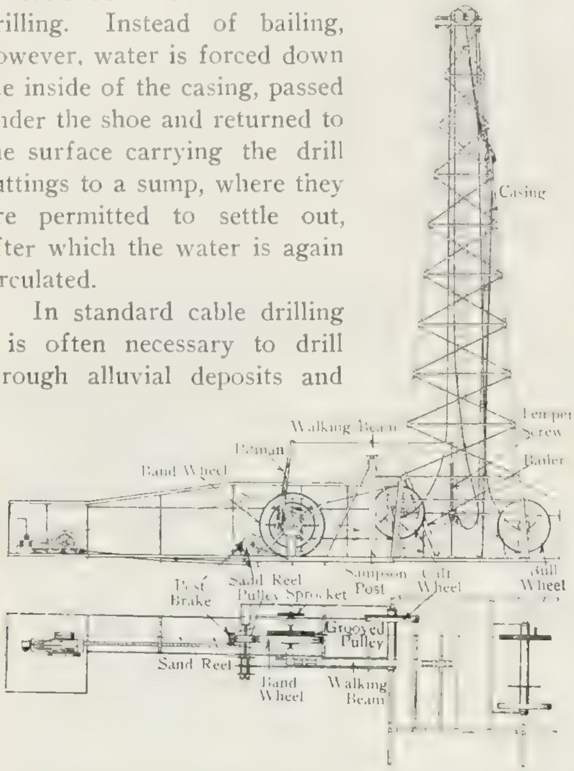

FIG. 5 PLAN AND ELEVATION OF APPARATUS ERECTED FOR CABLE DRILLING

Soft spots, quick-sand and water bearing strata may be met with as drilling progresses, and it then becomes necessary to haul the tools from the well and lower a second column of pipe within the first; the diameter of pipe being so selected that the column last placed will readily pass through the preceding string. This casing will be lowered until it completely seals off the well. As succeeding bad spots are met it is necessary to go through the same operation until in final form the well is made up as is shown in Fig. 6. One point which becomes apparent is that as succeeding strings of casings are lowered into the well, smaller diameters of drilling tools must be used, and usually the difference in the weights of the tools more than counterbalances the increased weight due to the increased length of cable.

In the above operations, where the bull wheel is depended upon to handle both the tools and the casing, every time it is desired to handle another column, the drilling tool cable must be unwound from the bull wheel and replaced by the casing cable. This would mean considerable delay under conditions in some territories such as those encountered in California, where the formations are particularly loose and sandy, and here the bullwheel has been supplemented by what is termed the "calf wheel," as shown in Figs. 5, 7 and 8. When both wheels are included as a part of the rig, the calf wheel is designed to develop heavy pulls at slow speed in order to handle the casing, while the bull wheel operates the tools at a somewhat higher speed. Whether the tools and casing are taken care of by the same or different wheels, the cycle of operation is the same, as follows:—One end of a 12 to 20 foot section of pipe 22 to 4 inches in diameter is raised from the ground and hauled up into the derrick until the lower end swings over the well. When properly centered it is lowered its full length, a collar fastened to its upper end and blocks arranged to hold it in position until another section can be raised and screwed on. Succeeding sections are screwed on and lowered until the column has reached the desired depth. In lowering casing, trouble is sometimes experienced in that the flexibility of the drilling tool permits it to avoid small hard spots. This leaves a shoulder which prevents the casing from sinking to the required depth, and under such circumstances it is the practice to raise the whole length of pipe two or three feet and permit it to sink back by its own weight. Repeated raising and settling wears away the obstruction and gives free passage. This is known as "jarring down the casing."

FIG. 6—SECTION OF A PIPE-ENCASED WELL

It is obvious then that where great depths are attained, a very severe duty is placed on the motor in that, in addition to the dead weight of the casing, there is considerable friction to be overcome. Reference to Fig. 3 shows that in hydraulic circulating drilling, the water is forced down within the casing and returned between the casing and the wall of the well, permitting the casing to follow the drill. Here there is no necessity for jarring casing, bailing or sand pumping, and the omission of these features eases the power requirements considerably. Such a system has a particular advantage where coarse gas-

bearing strata or quick sand are encountered, in that by mixing mud with the water and putting the water under pressure, the mud can be forced back into the sand and so cement off the well. Different degrees of porosity of rock and sand and varying gas pressures demand pumps having a wide range of pressure and volume. Usually two pumps are connected so that they may be operated separately or together, so that should one pump fail, another will be available for circulating the water sufficiently to prevent the mud from settling and imbedding the casing and tools.

Although cable drilling is very efficient in hard igneous formations, it is not adapted to drilling in shell formations, sand or mud. In this latter field the hydraulic rotary system is best suited. In this method the tool rests on the rock surface, cutting is accomplished by rotation and water is forced down the pipe to wash away the drill cuttings. The method of holding and rotating the drill is shown in Fig. 9. Here, as in the hydraulic circulating system, the water can be impregnated with clay and operated under sufficient pressure to force the clay back into the sand and porous rock. In this way the hole can be sufficiently well plastered off to avoid the need of casing until the final depth is reached. Since the tool is carried at the bottom of a column of four-inch pipe, the hole it bores must be straight. There is then no occasion for jarring casing, and the pipe readily slides down the clay plastered sides of the well. There may be occasions, however, when the pumps are not of sufficient

FIG. 7—CALF WHEEL [illegible]

capacity to handle excessive unexpected gas or water pressures and are unable to seal off the well. In such cases it may be necessary to put in casing below the trouble point. The well completed, however, and the last casing inserted to the bottom, the shorter columns may be pulled out for use on other wells. Such work is usually not so severe as jarring down casing [illegible] stops may be required in a short space of time. The very heavy duty incurred in all rotary drilling is in the matter of raising the whole column of four-inch pipe to change drilling cutters. In hard and widely varying shallow formations this may mean frequent changing of tools and when operating at depths below

FIG. 8—HOISTING WELL CASING
Calf wheel and drum in the background

two or three hundred feet imposes a very heavy duty on the motive power. By raising the tool and stem at slow speed this power requirement can be kept down to approximately three times the drilling requirement.

With a change of cutting tool it will probably be found necessary to change the cutting speed, since in rotary drilling there is one most effective speed for each degree of hardness.

With any of the above methods, once the "pay sand" (oil producing sand) is reached it only remains to explode a charge of nitroglycerine in or below the

TABLE I—DRILLING OPERATIONS

Cable Drilling.	Hydraulic Circulating Drilling	Rotary Drilling
Spudding	Spudding	
Drilling	Drilling	Drilling
Bailing		
Casing	Casing	Circulating Water
—Driving pipe	Circulating Water	Casing
—Jarring casing		

sand to open up a well into which the oil may collect, so permitting the foreign material it carries to settle out. A pump is lowered at the end of tubing and the oil conveyed to the surface through this tubing.

[illegible]

Spudding, drilling and bailing may require band wheel speeds anywhere from 18 to 75 r.p.m., depend-

ing on the depth of the well. This variation cannot be had with an alternating-current motor except at a sacrifice of good performance and complication of design. Two types of alternating-current motor may be used to give this speed range; one a two-speed, variable speed motor in which two pole combinations are depended on to give two different speeds, while the

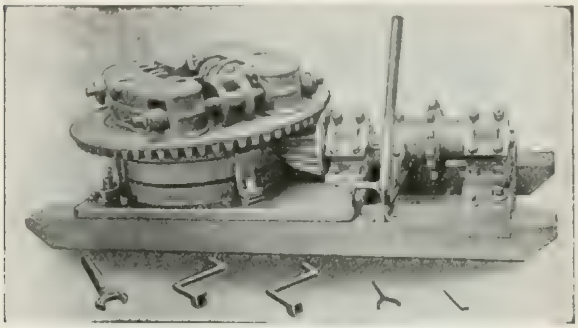

FIG. 9—ARRANGEMENT FOR HOLDING AND ROTATING THE PIPE IN CIRCULATING WATER ROTARY DRILLING

insertion of a resistance in the secondary gives reductions up to 50 percent from either speed; or a double stator motor, in which the stators of two motors are placed side by side around a common rotor, and one stator is rotated relative to the other to obtain different speeds. Either type of motor is very special and expensive, and it has been found a better proposition to use a two speed mechanical gear changing device in conjunction with a variable speed motor, for in this way the required speed range can be met in an efficient and less expensive manner.

This speed range can be met by a direct-current motor in an efficient manner without recourse to a mechanical speed changer, by means of field control. To date, however, the application of direct-current motors to drilling has been limited to shallow wells where portable drilling traction rigs are used, power being developed by means of a gas engine driven generator mounted on the rig.

While drilling requires a wide, yet close adjustment of speed, jarring down the casing gives rise to the most severe service encountered in drilling operations, and next to this comes the matter of hauling the drilling stem of a rotary drill from great depths. A better understanding of the relative power requirements in drilling operations and the period of time over which they extend, may be obtained by inspection of an actual power chart, Fig. 10, obtained when drilling at a depth of 1 215 feet, using an eleven and five-eighths bit. The motor windings were so arranged that they could be connected in star for continuous operation, and in delta for very heavy torques on a one-half hour rating basis. The chart shows that from 11 to 11:10 A. M. they were drilling, after which an operation took place which looked as though it might be handling of casing; this was followed by three bailing operations along about 11:30, using the delta connection, and at 11:50 drilling was resumed. At 1 P. M. it appears that they were working on the casing in an effort to jar it down. A series of such cycles as are shown here are typical of drilling operations, subject to exceptions such as fishing for lost tools. It is seen that on a basis of average power requirements the power taken in drilling is approximately one-third that required for bailing, hauling the tools from the well and jarring down casing.

The power required in drilling is more or less continuous in character, while that required in other operations is very intermittent. To meet these requirements with the ordinary type of motor would necessitate selecting a unit of sufficient capacity to take care of the peaks. It is evident that a motor chosen on this basis would be rather inefficient when drilling, a serious matter where purchased power is used, for the drilling load represents the larger percentage of the total running time. To avoid this condition, the special star-delta motor mentioned above and shown in Fig. 11 has been devised. Such a motor will efficiently develop intermittently three times the horse-power that it can carry continuously. In actual practice, efficiencies of 88 to 90 percent are obtained on the star connection, with a pull-out torque of twice the full load torque. When delta-connected, the motor will develop momentarily several times the star-connected full-load torque, due to the increased voltage per phase impressed on the windings. The change from star to delta is made by means of a double-throw switch mounted on the motor frame.

Where it is desired to use direct current the motor can be designed with series characteristics except that sufficient shunt turns are added to prevent the motor running away on no load. In such a design the limiting value of the torque developed depends on the commutating ability of the motor, since

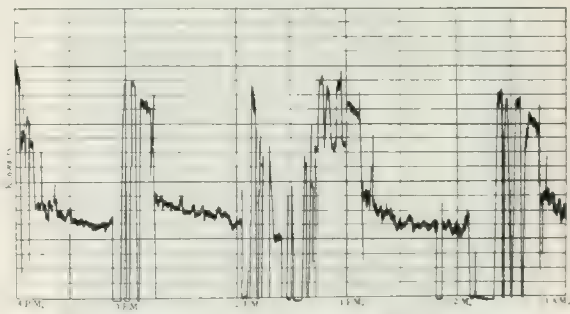

FIG. 10—CHART SHOWING RELATIVE POWER REQUIREMENTS AND LENGTHS OF TIME FOR EACH OPERATION IN OIL WELL DRILLING

The steady application of smaller amounts of power represents drilling; the larger peaks represent bailing or pulling casing.

the heavy pulls come on very intermittently. By the use of commutating poles, the capacity of the motor is augmented considerably. The use of a motor of series characteristics is particularly adapted to drilling from the beam in that as the load comes on in picking up the tool, the motor slows down, and the instant the load is released, which occurs soon after

the beam has moved up one-third its travel, the motor speeds up, so that when the tool is ready to drop the motor is letting out slack and the tool falls free and unrestrained. It is the free fall of the tool that gives rise to the most effective blow in drilling.

To obtain the close adjustment of speed required in any system of drilling requires a special control for the alternating-current motor, while a drum controller,

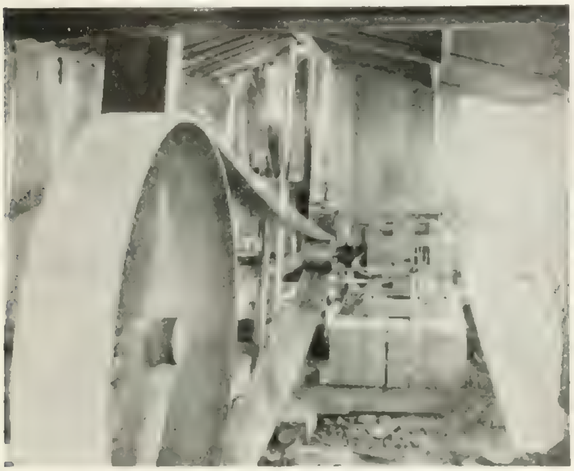

FIG. 11—SPECIAL STAR DELTA CONNECTED MOTOR DEVELOPED FOR OIL WELL DRILLING

similar to that used in operating machine tools may be used with the direct-current motor.

Two types of control have been found very efficient for use with alternating-current motors, depending upon the conditions surrounding the application, namely, the liquid rheostat, and the double drum control. The liquid rheostat is particularly adaptable to drilling in that it provides an infinite number of steps between 100 and 50 percent speed, has few wearing parts and low cost of up-keep. A type developed for use in California is shown in Fig. 12. In this type of rheostat, a drum is carried on an extension of the electrode shaft to close, open and reverse the primary circuit. When larger currents are required than can be opened by the drum contacts, the drum is used to operate the control circuits of magnet type switches. The secondary resistance is adjusted by raising or lowering the electrodes in the electrolyte. When the electrodes are almost completely submerged, projecting lugs engage spring contacts and short-circuit the secondary, giving maximum speed. The rheostat is actuated through a sheave wheel by a wire rope from another sheave wheel on the headache post, at the well.

The liquid rheostat requires good water and sufficient attention to maintain the proper constituency of the electrolyte. Where neither can be depended upon, a double drum rheostat is more advisable, the main drum cutting out the secondary resistance in large steps, the intermediate steps being regulated by the auxiliary drum.

In drilling with direct-current motors, the speed variations are obtained by field control. An ordinary type of drum controller is furnished in which the first three steps cut out armature resistance and the remaining 12 points vary the field resistance. When using a motor having a three to one speed ratio, the field resistance is so arranged that in moving the control handle from the *3rd* to the *14th* point, a 100 percent increase in speed is obtained, and then by moving from the *14th* to the *15th* point a 50 percent additional increase is obtained for raising the tools from the well. In other words, there are eleven steps to obtain a 100 percent increase in speed for drilling, and this is ample for the depth of well on which the direct-current motor finds application.

The type of motor and control developed for cable drilling is admirably adapted for operating the rotary drill, raising the drill stem and driving the circulating pumps. Because of the danger of losing the tool and possibly the well, should the circulation of the water stop, two motors are furnished in duplicate; one for drilling, handling the stem and casing; the other, for driving the two pumps. While the pumps do not usually require so large a motor as is needed in the other operations, especially at depths beyond 2 500 feet, it has been found advisable to use duplicate motors, so that only one set of repair parts need be carried. To protect himself in case of power failure, where central station current is purchased, the operator is very apt to demand a penalty sufficiently large to insure his tools and well. Failing in this he is warranted in maintaining a gas engine driven generator of sufficient capacity to keep the pump motor going at times when the power is off the lines.

In concluding the subject of drilling operations and their influence on the selection of the electrical

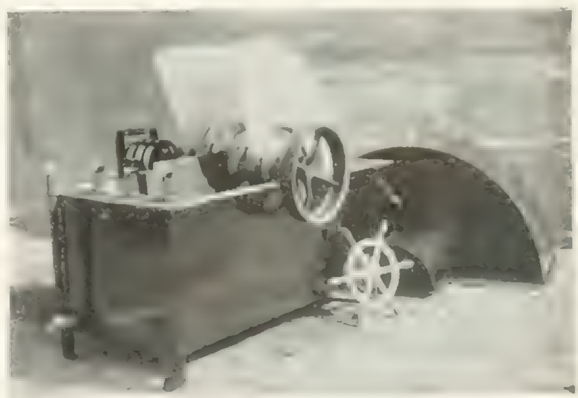

FIG. 12—WATER RHEOSTAT FOR OIL WELL DRILLING

equipment it should be noted that all drilling operations have not been covered, but only such as determine the most adaptable and efficient type of motor and control. The characteristics and capacities so determined may not be the best for numerous special operations that may arise, but there is every reason to believe that equipment so selected will show the best average results when the well has been completed.

Shop Testing of Electrical Apparatus—XV

INDUCTION MOTORS—(Cont.)

THE SYMBOLIC METHOD

THE circle diagram method is a very satisfactory method of testing induction motors of less than ten percent slip, particularly when they are being tested in quantities. For motors with large slip, and for small motors with high primary resistance, the ordinary circle diagram is not so satisfactory, and the Branson method or the Steinmetz' symbolic method is often used. For the latter method, practically the same data is obtained on the test floor as is necessary for the construction of the circle diagram and that will be designated as follows:—

r_o primary resistance
$I_{oo} =$ primary current, motor running light
$E =$ normal impressed voltage
$W_o =$ watts input, motor running light
$I_L =$ primary current, rotor locked
$W_L =$ primary watts, rotor locked
$\cos \Phi_L =$ power-factor, rotor locked.

TABLE VII—TEST DATA AND CALCULATED CONSTANTS

$E=$	440.	$r_1=$	0.191
$I_o=$	27.7	$X_o=$	15.8
$r_o=$	0.1118	$X_L=$	0.496
$W_o=$	1140.	$x_o=$	0.248
$I_L=$	756.	$x_1=$	0.248
$W_L=$	173000.	$r_o'=$	1.367
$\cos \Phi_o=$	0.0935	$x_o'=$	15.55
$\cos \Phi_L=$	0.520	$g=$	0.0056
$R_o=$	1.479	$b=$	0.0637
$R_L=$	0.303	Pull-out slip$=$	0.376

The motor performance may then be obtained from the test data as given in Table VII as follows:

Total impedance, $Z = \frac{E}{I_L}$

Total resistance, $R = Z \cos \Phi_L$

Total reactance, $X = \sqrt{Z^2 - R^2}$

Let $x_o =$ primary reactance
$x_1 =$ secondary reactance expressed in terms of the primary
$r_1 =$ secondary resistance expressed in terms of the primary.

Then it is assumed that,

$$x_o = x_1 = \frac{X}{2} \text{ and } r_1 = R - r_o.$$

Let $I_o =$ total primary current
$I_1 =$ secondary current reduced to terms of primary
$P_o =$ power output
$P_1 =$ power input
$T =$ torque in lbs-ft.
$s =$ slip in percent.
$b =$ susceptance
$g =$ conductance.

The usual method of obtaining the values of g and b is by the formulae,—

$$g = \frac{W_o}{E^2} \text{ and } b = \frac{I_{oo}}{E}$$

The following method, however, taking the no-load values, will be found to give better results, especially in the case of machines with high drop in the primary:—

No-load impedance, $Z' = \frac{E}{I_{oo}}$

No-load resistance, $R' = Z' \cos \Phi_o$

No-load reactance, $X' = \sqrt{(Z')^2 - (R')^2}$

Let $r_o' = R' - r_o$
$x_o' = X' - x_o$

Then $g = \frac{r_o'}{(r_o')^2 + (x_o')^2}$ and $b = \frac{x_o'}{(r_o')^2 + (x_o')^2}$

Having obtained the above constants for the motor as indicated in Table VII, the complete performance may be calculated by the following formulae:—

Let $a_1 = \frac{s\, r_1}{r_1^2 + s^2 x_1^2}$

$a_2 = \frac{s^2 x_1}{r_1 + s^2 x_1^2}$

$b_1 = a_1 + g$

$b_2 = a_2 + b$

$c_1 = 1 + r_o b_1 + x_o b_2$

$c_2 = r_o b_2 - x_o b_1$.

Then $I_o = E \sqrt{\frac{b_1^2 + b_2^2}{c_1^2 + c_2^2}}$

$I_1 = \sqrt{\frac{a_1^2 + a_2^2}{c_1^2 + c_2^2}}$

$P_o = \frac{E^2 a_1 (1 - s)}{c_1^2 + c_2^2}$

$P_1 = \frac{E^2 (b_1 c_1 + b_2 c_2)}{c_1^2 + c_2^2}$

$T = \frac{E^2 a_1 \times 5250}{(c_1^2 + c_2^2) \times \text{synchr. r.p.m.} \times 746}$

Starting Torque $= \frac{(P_L - I_L r_o) \times 7.04}{\text{Synchr. r.p.m.}}$

Efficiency $= \frac{P_o}{P_1}$

Power-factor $= \frac{P_1}{E \times I_o}$

Slip at pull-out $= \frac{r_1}{\sqrt{r_o^2 + (x_o + x_1)^2}}$

It is obvious that these values must be obtained complete for each point in the motor performance. It is usual to base the calculation on the values of slip, all other quantities then being determined from the foregoing formulae. A complete calculation by this method from the test data given is shown in Table VIII. These calculations are for the same motor to which the prony-brake method and the circle diagram have already been applied in this article and it is interesting to compare the results by all three methods as given in Table IX.

SINGLE-PHASE MOTORS

Single-phase induction motors differ from polyphase motors in that, as such, they have no starting torque; machines smaller than one horse-power are usually started by means of a split-phase starting winding of relatively high resistance, which is cut out by a centrifugal device after a certain speed is attained; while larger sizes are ordinarily started up as repulsion motors, the commutator being short-circuited by a centrifugal device. On account of the

complicated distribution of fluxes in the single-phase motor, the circle diagram is not applicable, without certain modifications, which make the results somewhat uncertain. The symbolic method is equally applicable to all types of motors, when modified to include the different starting conditions. For the small outputs for which single-phase induction motors are ordinarily built, however, the brake test is very well suited and on account of its simplicity that method of testing is almost always used. Especial

TABLE VIII—PERFORMANCE BY SYMBOLIC METHOD

S	0.015	0.022	0.032	0.045	0.055	0.376
S^2	0.000225	0.000484	0.001025	0.00203	0.00302	0.1415
Sr	0.00287	0.00421	0.00611	0.00860	0.0105	0.0719
r	0.0365	0.0365	0.0365	0.0365	0.0365	0.0365
S^2x	0.000014	0.000030	0.000063	0.000125	0.000186	0.00874
r_1	0.036514	0.036530	0.036563	0.036625	0.036686	0.04524
a	0.0735	0.1151	0.1673	0.2348	0.286	1.59
g	0.0056	0.0056	0.0056	0.0056	0.0056	0.0056
a_1	0.0841	0.1207	0.1729	0.2404	0.2916	1.5956
$S x$	0.000056	0.000120	0.000254	0.000503	0.00075	0.0351
a_2	0.00153	0.00329	0.00695	0.01375	0.0204	0.776
b	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637
b_2	0.06523	0.06699	0.07065	0.07745	0.0841	0.8397
r_2b_1	0.00941	0.01350	0.01935	0.0269	0.0326	0.1785
x_2b_2	0.01615	0.0166	0.0175	0.0192	0.0209	0.208
c_1	1.02556	1.03010	1.03685	1.0461	1.0535	1.3865
r_2b_2	0.00730	0.00748	0.00791	0.0086	0.00941	0.0939
x_2b_1	0.02087	0.0300	0.0429	0.0597	0.0724	0.396
c_2	—0.01357	—0.02257	—0.03499	—0.05104	—0.06299	—0.2921
b_1^2	0.00709	0.0146	0.030	0.058	0.084	2.55
b_2^2	0.00425	0.00443	0.00499	0.0060	0.0072	0.706
$b_1^2+b_2^2$	0.01134	0.01903	0.03499	0.06400	0.09156	3.256
c_1^2	1.052	1.062	1.075	1.095	1.110	1.922
c_2^2	0.000183	0.000509	0.00123	0.00261	0.00397	0.0855
$c_1^2+c_2^2$	1.052183	1.0625	1.07623	1.09761	1.11397	2.0075
$b_1 c_1$	0.0864	0.1243	0.1795	0.252	0.307	2.21
$b_2 c_2$	—0.000885	—0.00151	—0.00247	—0.00395	—0.0053	—0.245
$b_1 c_1 - b_2 c_2$	0.085515	0.12279	0.17703	0.24805	0.3017	1.965
$a_1 (1 - S)$	0.0774	0.1126	0.1620	0.2246	0.270	0.992
P_2	14250	20500	29200	39700	47000	96000
Efficiency	90.25	91.75	91.50	90.50	89.50	
I	45.60	58.90	79.60	106.10	126.00	
P_1	15800	22350	31900	43800	52500	
Power-factor	78.75	86.20	91.10	93.75	94.50	
Brake hp	19.1	27.50	39.10	53.10	62.90	128.50
R.P.M.	493	489	484	478	473	312
Torque	203	296	424	583	698	2160

Starting torque ÷ full-load torque = 2.81
Maximum torque ÷ full-load torque = 3.95
Starting amperes ÷ full-load amperes = 2.69

care must be exercised that the braking conditions do not vary during the test, but with suitable precautions, consistent and accurate results are possible. The tests made, after the usual mechanical inspection, are cold resistance; locked saturation and running saturation on each winding separately; locked and pull-out torque; and a brake test, increasing the load by steps to one and one-quarter load. These tests are run in the same manner as for a polyphase motor, and from them the complete performance of the motor may be obtained.

[illegible]

Another method of obtaining the performance of both single-phase and polyphase motors combining somewhat the advantages of the purely symbolic methods and the diagram methods was presented by Mr. W. J. Branson,* in June, 1912. The advantage of the method lies in the fact that the readings may be obtained quickly and accurately, the few empirical constants used in the calculations being the result of long and careful investigations. The complete performance may be determined readily by any one familiar with elementary mathematics, and ordinary drawing instruments. This method of calculation is more frequently applied to the design of motors but it is equally valuable in working up the results of test.

TABLE IX—COMPARISON OF MOTOR PERFORMANCE BY CIRCLE DIAGRAM, BRAKE TEST AND SYMBOLIC METHODS.

Full Load of Values	Circle Diagram	Brake Test	Symbolic Method
Volts	440	440	440
Amperes	101	102.1	100
Percent power-factor	93.2	93	93.0
Real horse-power	55.5	55.9	55.1
Percent efficiency	90.2	89.5	90.8
Brake horse-power	50	50	50.0
Percent slip	4.6	5	4.3
R. p. m.	477	475	479
Full-load torque	550	552	548
Starting torque÷F. L. T.	2.78	2.9	2.81
Maximum torque÷F. L. T.	3.89	3.5	3.95
Starting amperes ÷ full-load amps	2.69	2.56	2.69

The data to be obtained on the test floor in preparation for working up the results of a single-phase induction motor by this method are as follows:—

E = rated voltage.
i_o = no-load amperes.
P_o = no-load watts.
i_L = locked amperes main winding.
P_L = locked watts main winding.
r_1 = primary resistance.
P_F = friction and windage losses.
i_{LS} = locked amperes starting winding.
P_{LS} = locked watts starting winding.
r_{1S} = resistance starting winding.

The characteristics to be determined from the above are:—

X_1 = primary reactance.
X_s = starting winding reactance.
r_2' = secondary resistance (locked).
r_2 = secondary resistance (running).
i_m = main field magnetizing amperes.
P_s = secondary copper loss.
P_i = motor iron loss.

Then $P_M = P_i \times 0.53$ = iron loss due to the main field.
$P_c = P_i \times 0.47$ = iron loss due to the cross field.

Let S_1 = amperes per inch.
S_2 = secondary amperes in terms of primary, per inch $= \frac{S_1}{K_P}$
(See below for K_P)
S_e = volts per inch.

*See proceedings of the A. I. E. E. for July, 1912, p. 1525.

The diagram Fig. 6 is constructed from the test data for the determination of these values. Lay off $LR' = \frac{P_l}{ES_1}$ perpendicular from some convenient point on OR', the horizontal. Then from L as a centre with a radius $OL = \frac{i_l}{S_1}$ cut OR' at O. At O lay off $OE = \frac{E}{S_e}$ perpendicular to OR'. Then from the point E lay off $ZE = \frac{i_l r_1}{S_e}$ * parallel to OL and draw OZ. Draw OH at right angles to OZ from O and lay off on it $OM = \frac{i_o}{2S_1}$ (approximately). Then construct a semi-circle through the points M and L with center on OH.

The above characteristics are then determined from Fig. 6 as follows:—

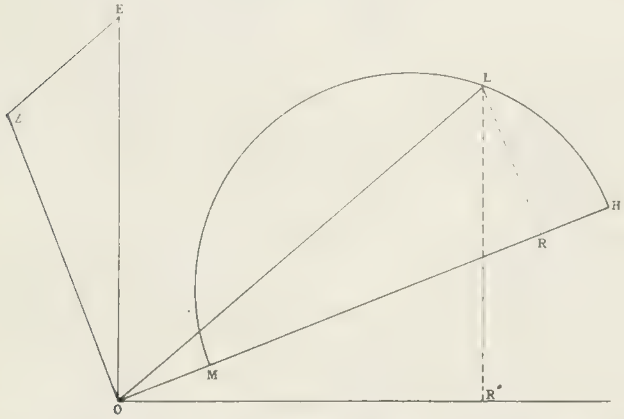

FIG. 6—PRELIMINARY DIAGRAM FOR THE DETERMINATION OF INDUCTION MOTOR CONSTANTS BY BRANSON'S METHOD

$$X_1 = \frac{E \times OZ}{OH \times OE \times S_1}$$

$$r_2' = X_1 \times \frac{LH}{ML}$$

$$r_2 = r_2' \times \left(\begin{array}{l} 0.8 \text{ for } 60 \text{ cycles} \\ \text{or } 0.9 \text{ for } 25 \text{ cycles} \end{array}\right) \text{(approximately)}$$

$$i_m = \frac{i_o \times E}{2E - i_o X_1} \times 1.03 \text{ (approximately)}$$

$K_r = 1 - \frac{i_m X_1}{E}$ and K_p [illegible] K_r

$$P_s = \frac{i_o^2 K_r r_2}{4}$$

$$P = P_o - (i_o^2 r_1 + \frac{i_o K_r r_2}{4} + P_f),$$

After the above characteristics have been determined in this manner, a new diagram as shown in Fig. 8 is constructed for calculation of the motor performance. To begin with, lay off $O'H = \frac{E}{X_1 \times S_1}$ and $O'M = \frac{i_m}{S_1}$ and $O'V = \frac{i_o}{S_1}$ both on $O'H$. Construct a semi-circle with MH as a diameter. From the value $\frac{r_2}{X}$, which has already been determined, the value $\frac{LH}{MH}$ can be obtained from Fig. 7. Then $\frac{LH}{MH} \times MH = LH$. Lay off LH from H to cut the circle at L, giving the locked point. Draw a circle through V, L and H, the centre C being determined

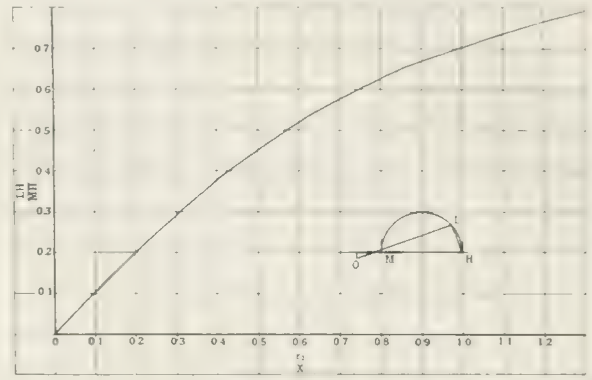

FIG. 7—THE CURVE USED FOR THE DETERMINATION OF $\frac{LH}{MH}$ IN THE CONSTRUCTION OF THE LOCKED POINT BY BRANSON'S METHOD

by the intersection of the bisectors of the chords VL and LH. The bisector of the arc VL then determines the point T of maximum torque. HT is then drawn and extended to cut the larger circle at N.

Draw a perpendicular to $O'H$ at O' and lay $O'O = \frac{P_m}{E \times S_1}$ and $OE = \frac{E}{S_e}$. From E draw a

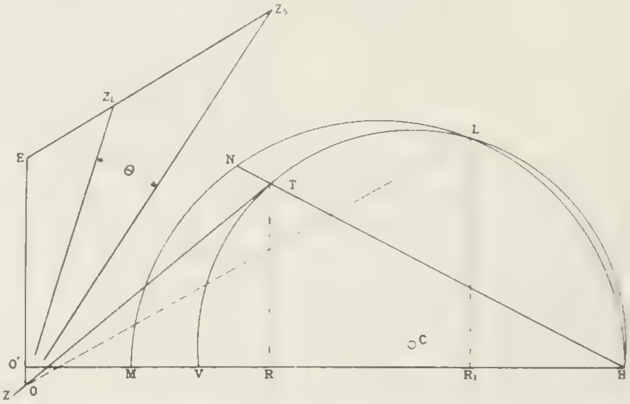

FIG. 8—COMPLETE DIAGRAM FOR THE DETERMINATION OF THE PERFORMANCE OF SINGLE-PHASE INDUCTION MOTORS

line parallel to OL and lay off $EL_1 = \frac{OL \times S_1 \times r_1}{S_e}$ and $EZ_s = \frac{OL \times S_1 \times r_{1s} \times X_1}{S_e \times X_s}$. The diagram is then completed by drawing OZ_1 and OZ_s and extending OT to Z making $OZ = \frac{OT \times S_1 \times r_2}{S_e}$.

The complete motor performance at any point may now be obtained from Fig. 8 in the manner outlined in Table X. In addition to the data obtained in this way the starting torque of the motor, which

*In laying off ZE, r_1 should be corrected to the temperature at which the locked saturation readings were taken.

involves both the main and the starting windings is determined from the following formula:—

$$\text{Starting torque} = 225 \frac{\text{I.R.} \times S \times I \times OH}{\text{Synchronous R.P.M.} \times OZ \times OZ} \sqrt{\frac{X}{X}} \times \sin\Theta, \text{ in oz-ft.}$$

Due to rapid change in the coefficient of friction of the brake the effective maximum torque as obtained by brake is about 92 percent of the calculated value and in the same way, due to the rapidly changing temperature during starting, the effective starting torque is only about 92 percent of the calculated value.

TEMPERATURE TESTS

Temperature tests are made to determine the heating of the motor for the condition under which it will operate. Motors for continuous duty are usually run under full load until constant temperature is reached, and then at 25 percent overload for two hours. Motors for intermittent operation are run for a length of time based on an estimate of the service conditions.

All motors except those of the very largest rating are loaded by being belted to a generator, the load on which can be readily adjusted over the range desired. Meters suitable to read the voltage, current and power should be connected in their proper places. Thermometers* that are to be read during the operation should be placed on the machine, and all precautions carefully observed.

In starting, a low voltage is first impressed on the machine sufficient to determine its direction of rotation. If incorrect, one phase is reversed; if correct, the motor should be gradually brought up to normal voltage, watching carefully in the meantime that both the motor and the generator used as load are operating in a satisfactory manner. Oil rings should be inspected to see that they are turning properly, the tension on the belt adjusted and the general operation noted. The field of the generator should then be closed and the load be brought up gradually to its normal value. A reading of current and speed is now taken, the voltage and frequency being held constant at their normal values. These should be read every hour during a continuous temperature run and each half-hour during overload runs. Temperatures of all stationary parts should be taken at these same intervals. Readings of power need only be taken two or three times during the full-load test and once only on overloads. The full-load test must be continued until all temperatures are constant as indicated by the identity of the temperatures at two successive readings. This usually takes from four to seven hours depending on the size and ventilation of the machine under test. From time to time during the run a careful inspection of the wiring and of the machines themselves should be made to make certain that no abnormal condition is developing.

The cause of any undue noises should be noted, and the ventilation tested to determine whether it is normal in all parts of the machine.

Before shutting down, preparations should be made for taking resistances immediately after the shut down; the thermometers and waste or pads for measuring the temperature of the rotating parts should be on the spot. The various operations should be assigned to individuals in such a manner that each will know what is expected, avoiding any unnecessary delay. In shutting down, whenever, possible, the power should be cut off from the motor, leaving the generator running under load; the motor will then come to a standstill very rapidly, while otherwise it would fan itself considerably, lowering its temperatures materially before it could be stopped.

Resistance should be taken between terminals, noting carefully between which leads each resistance is taken. If the secondary is wound, resistances should also be taken in like manner between its rings. The time of the last reading on the temperature sheet should appear with the record of resistances.

Readings of all thermometers should be made as soon as possible and every two minutes thereafter

TABLE X—CALCULATION OF A SINGLE-PHASE MOTOR

No.	Item	Derivation
1	OT	From Fig. 8
2	MT	From Fig. 8
3	MN	From Fig. 8
4	NT	From Fig. 8
5	TH	From Fig. 8
6	TR	From Fig. 8
7	OE / ZE	From Fig. 8
8	$MN \frac{r_2}{X_1}$	$(3) \frac{r_2}{X_1}$
9	$NT \frac{r}{X}$	$(4) \frac{r}{X}$
10	$TH - MN \frac{r_2}{X_1}$	$(5) - (8)$
11	R. P. M.	$\sqrt{\frac{(10)^2 - (9)^2}{(5)\ (9)}}$ or $\sqrt{\frac{(10)^2}{(6)}}$
12	Primary Amperes	$(1) \times (7) \times S_1$
13	Secondary Amperes	$(2) \times (7) \times S_2$
14	Sec. Copper Loss, A	$(MV \times S_2)^2 r_2 \left(\frac{(11)}{\text{Synch.R.P.M.}} \times (7)\right)^2$
15	Sec. Copper Loss, B	$(13)^2 \times r_2$
16	P_c	Already determined
17	P_i	Already determined
18	P_w	Already determined
19	Primary Copper Loss	$(12)^2 \times r_1$
20	Secondary Input	$(6) \times (7)^2 \times S_1 \times E$
21	Total Input	(18)+(19)+(20)
22	Total Losses	(14)+(15)+(16)+(17)+(18+(19)
23	Output	(21)—(22)
24	Torque	$(23) \times \frac{112.7}{(11)}$ (ounce-feet)
25	Efficiency	(23) divided by (21)
26	Apparent Watts	$(12) \times E$
27	Power-Factor	(21) divided by (26)

*When item (9) is very small compared to item (10), item (9) may be omitted in calculating item (11).

*See the JOURNAL for Jan., '13, p. 67.

until they start to go down, the highest reading being marked by a circle.

Before starting on the 25 percent overload temperature test, the motor is heated up under full load until the temperature of the stator copper and iron become the same as at the end of the full-load test. It is then run the required two hours on the overload, semi-hourly readings being taken. Temperatures are read as on the full-load run, especial care being taken to get readings as soon as possible after shut-down.

In the case of motors of such large capacity that they cannot be given tests under normal load, compromise tests are taken. The chief of these is the circulating current test. The motor is driven from an outside source in the direction of rotation opposite to normal. The voltage is raised to such a value as to cause the specified current to flow. A temperature test is taken in the ordinary way under these conditions both at normal and at 25 percent overload current.

COMMERCIAL TESTS

These tests are taken primarily to prove that the motor under test is free from electrical or mechanical defects, and that it will do the work for which it was designed, in a satisfactory manner. In general, the tests required are as follows:—

1—Cold resistance of all windings.

2—In cases of wound rotors, a reading of secondary voltage at normal primary voltage, the secondary circuit being open.

3—An observation run of one-half hour at no-load normal voltage.

4—A reading of speed, current and watts at no-load normal voltage.

5—A reading of current and watts, rotor of motor being locked.

6—Mechanical inspection.

7—Insulation test.

The electrical test should be checked to the standard engineering test previously taken on the particular design in hand. The resistance may vary ten percent from the value then given, no-load and locked amperes ten percent, the watts 15 percent. The secondary voltage on wound secondary motors should check within five percent of the standard value.

At convenient times during the foregoing tests a careful mechanical inspection should be made. The balance, end play and lubrication are the chief features to be noted. The air-gap adjustment should be uniform, though a slightly larger gap at bottom than at top is not undesirable. The condition of these features should all be noted on the test sheets. The tester should note in addition the size, alloy and number of rings on squirrel-cage secondaries, also whether soldered or not soldered. The type of blowers, if any, whether the machine is noisy or quiet and any other features that may be peculiar to the case in hand.

After all tests are completed, though preferably while the machine is hot, it must be tested for grounds. The insulation between the windings and the frame is subjected to a high voltage; this voltage is usually 1 500 volts for motors under 550 volts and 5 000 for those up to 2 200 volts.

In the commutator type of single-phase induction motors, the governor should be adjusted to throw out between 93 and 97 percent of synchronous speed. This throws the brushes off the commutator and short-circuits the secondary, enabling the machine to run as a straight induction motor. This adjustment is usually made before being assembled with the rest of the motor but must be tested also after being assembled. The action must be very positive. That all parts are thrown into their proper positions should be particularly noted.

The running position of the brushes is determined by the starting torque desired. The brushes are shifted from the neutral point until the necessary torque has been obtained. This position should be obtained for both directions of rotation and marked clearly with a chisel. On these motors shifting the brushes from one side of neutral to the other reverses the direction of rotation.

SPECIAL TESTS

In cases where a guarantee has been made with respect to some particular characteristics, such as starting torque, pull-out, speed, etc., and a standard motor is to be furnished, such tests are made in addition to the standard commercial tests as will establish the fact that the motor selected will meet the guarantees. Where power-factor or efficiency have been guaranteed, it will be necessary to take data sufficient for constructing the diagram, namely, cold resistance, running and locked saturations. Guarantee readings of starting and pull-out torque in large motors will also be determined from the diagram. In the smaller motors when more convenient they may be determined by test. In cases of elevator motors or others with very intermittent rating, the value of torque and slip should always be verified by actual test. Temperature guarantees may not be checked if sufficient tests have already been made on machines of the same design to insure that the limits given have always been met safely. That the machine is safe, however, must not be taken for granted but the past records must be investigated in each case.

THE ELECTRIC JOURNAL

VOL. XI APRIL, 1914 No. 4

The Use of Reactance Coils

A very interesting group of papers in this issue of the Journal deals with various features concerning the use of reactance coils. This series of articles is a timely one on account of the unusual interest that is now being displayed by electrical engineers in general over the use of such coils in modern electrical systems. It is astonishing to note the change in attitude of mind towards the use of reactance coils that has overtaken electrical engineers during the past few years. Time was, in the earlier days of our industry, when reactance in alternating-current circuits was avoided as a pestilence. On analysis it is found that the change in the attitude of mind of the electrical engineers of the present day is simply one of the results of the tremendous growth that has taken place in our industry during that period.

When the alternating-current generating units were small, it was the question of voltage regulation that gave rise to many of the difficulties in the operation of the alternating-current systems. In the early days, the use of compensated alternators was general; that is, alternators which were equipped with a series winding in which circulated the commutated series current, or one proportional to it, so as to secure a compounding effect with load. It was noted that the power-factor of the load had a marked influence upon the voltage of such machines, and that the increase in field ampere-turns necessary with low power-factor was much greater than that necessary with loads of high power-factor. It was noted, further, that the power-factor of the load had a marked influence, not only upon the compounding of these small alternators, but also upon the operation of their commutators. It was reactance that gave rise to bad power-factor, and hence it was only natural that a prejudice should spring up among electrical engineers against the use of reactances.

As time went on, and generators became larger, the problem of securing proper voltage regulation became an easier one, for the simple reason that a given change in load became a smaller and smaller proportion of the capacity of the generating system, and the conditions which gave rise to serious voltage fluctuations with the earlier and smaller machines were found to have but little effect upon the later and larger generators. And then the continued increase of generator capacities at last brought us to a point where the use of reactances became desirable, rather than detrimental. It was observed that the heavy short-circuit currents in some of the early large generators were sufficient to cause distortion of their armature windings. The remedy which was sometimes applied was to reduce the instantaneous short-circuit currents in these machines by placing reactance coils in series with them. However, this remedy was a more or less temporary one, since it was found that by proper design of their electrical characteristics, and by the use of proper bracing methods, generators could be produced which would be able to take care of themselves upon short-circuit without the use of reactance coils in series. A further analysis, however, shows that the reactance coil has an important place in the protection of modern generating systems, but that its proper position is not in series with the generator leads but in series with the feeders. In this location it protects the remainder of the system from the effects of a heavy short-circuit current on any one feeder. Thus, this location of reactance coils has, as its object, the protection of service rather than the protection of apparatus.

This group of articles includes descriptions of how modern reactance coils are produced, of the mechanical stresses that occur upon coils, of the transient conditions that take place during the first few cycles of short-circuit, and also of a very interesting series of tests which were conducted upon reactance coils recently.

P. M. LINCOLN

The Artificial Ventilation of Generators

The companion articles in this issue of the Journal by Messrs. Gilman and Stephenson call attention to a very important question; important both from the standpoint of design and operation. The question of proper air supply has been given a great deal of attention by *machine* designers; it has been given far too little attention by *station* designers. Proper ventilation within the machine, however, becomes of little value unless ventilation design outside of the machine has been adequately considered. In a station of more than 100 000 k.v.a. capacity, recently completed, the thoroughness with which many details of design and construction had been worked out was apparent; at the same time no special provision had been made to insure an adequate supply of air for the large generators. This failure to consider machine ventilation in the station design has been more usual in large water power stations than in steam stations, particularly those steam stations using horizontal turbine prime movers. But in

all classes of large stations, more attention is now being given this important feature. In a number of recent stations containing large vertical-shaft water-turbine-driven generators, adequately large air ducts have been provided leading from the exterior of the station to the chamber immediately below the generator. In horizontal shaft units, experience has shown the necessity of ventilating the generator foundation pits if there is any opportunity for hot air discharged from the generator mixing with the generator cooling air. In a recent Pacific Coast installation using 12 500 k.v.a. horizontal shaft generators, enclosed air ducts have been provided leading from outside the station to the interior of the generators, thus separating entirely the cooling air from the heated discharged air. These generators were provided with the same form of enclosed end bells with air intake chambers that have been usual with horizontal steam turbine-driven generators for some years. It is a welcome sign that the old neglect of this important feature of station design is giving way before a more intelligent treatment of the question.

The desirable size of ventilating ducts for the large generators now commonly used often becomes a serious inconvenience and the ability to use higher air velocities and consequently smaller ducts, as pointed out by Mr. Gilman, if the fans are located at the duct entrance instead of at the generator shaft, is an advantage of the external motor-driven fan of considerable importance to the station designer.

While the first essential of good machine ventilation is an adequate supply of air of some sort, it is a further advantage if the air that is delivered to the generator can be cool and clean. This is more often a difficult problem in a steam station, and particularly in a steam station in a soft-coal district, than in an hydraulic station. The water-spray type of air filter or washer mentioned by Mr. Gilman, and described in a specific installation by Mr. Stevenson, affords an entirely practical means for cleaning and cooling the air supply for even the largest stations. Cloth filters of various forms have been in use in Europe for five years or more but, while considered in a number of instances in this country and actually tried in a few, their obvious disadvantages have prevented their adoption by American engineers. The large space required and the excessive labor cost to keep them even reasonably clean have been the main reasons for their non-adoption, but the air pressure required to force the air through them and the fire risk involved have been contributing disadvantages. On the other hand, the water-spray type of washer requires practically no labor for maintenance, takes up relatively little space and offers a negligible air resistance. The supply of *clean* and *cool* air has such important advantages from the standpoint of generator operation, and this method of air washing and cooling has so few counterbalancing disadvantages that its extensive introduction in large steam stations should be rapid.

Experience has shown that no fear need be had that moisture in sufficient quantities to be dangerous will be introduced into the generator. In fact a future development of great potential importance in generator ventilation may be the deliberate introduction of free water vapor into the cooling air to secure the great cooling effect incidental to its evaporation.

F. D. Newbury

Air Conditioning Apparatus for Turbo-Generators

The use of air conditioning apparatus in connection with modern turbo-generators is of interest to both the operating engineer and the manufacturer; to the former because it means clean, cool running machines and to the latter because it means added assurance that machines will stand up to guarantees and "deliver the goods" with a minimum of maintenance and attention. In industrial localities where the air contains a relatively large amount of solid material in suspension turbo-generators should be cleaned frequently. Thus, at the Brunots Island power plant of the Duquesne Light Company, it has been the custom to clean the generator every two to four weeks, which means an expense of approximately seventy-five dollars per year per machine. With clean air entering the generators, the frequency of cleaning was safely reduced to once every ten or twelve weeks with a corresponding reduction in expense. As a matter of regular inspection, however, the turbo-generators are opened up at least once a month and a thorough examination made of insulation, bracing, clamps, spacing blocks, etc., but the expense of such inspection must be considered apart from the question of cleaning.

The accumulation of dirt within air-cooled electrical apparatus is exceedingly objectionable, for the reason that the ventilation ducts become obstructed and the radiation surfaces become more or less completely covered with a deposit of poor thermal conductivity. The result is not only a reduction in the volume of air passing through the ducts but a reduction in the amount of heat conducted from the iron and copper of the machine to the radiating surface for a given heat gradient. This is particularly true of modern high capacity turbo-generators where the cooling of the internal parts of the machine is so largely dependent upon a continuous and liberal supply of air. Not only does the accumulation of dirt mean higher operating temperatures but an impairment of insulating qualities, particularly in high voltage generators. Finely divided dust particles will penetrate the smallest crack and crevice in the insulation, with the possible formation of brush discharges and consequent heating of the insulation and eventual break-down. The accumulation of dirt in the rotor will very greatly reduce the insulation resistance of the field winding and possibly lead to the formation of arcs during periods of short-circuits. A thorough cleaning of a turbo-generator rotor in service only nine months has been known to

increase the insulation resistance of the field winding from 300 000 to 9 000 000 ohms.

Aside from the standpoint of cleanliness, the air conditioning apparatus is distinctly advantageous in some localities where it effects a considerable reduction in the temperature of the air entering the machines through the process of evaporation. Take for example, our own experience in Pittsburgh. During the summer months there are ordinarily three load peaks on the Duquesne Light Company's system; one about 8 A. M., one about 5 P. M. and the third at 8 P. M. The morning and evening peaks run about the same and somewhat higher than the evening peak. The Pittsburgh Weather Bureau reports show an average relative humidity of 75 percent at 8 A. M. and 62 percent at 8 P. M. for the whole year, with little variation from month to month. The average temperature for June, July and August runs about 66 degrees F. at 8 A. M. and 76 degrees F. at 8 P. M., while the average maximum temperature for these three months is about 92 degrees. During the morning peak, air at 66 degrees and 75 percent relative humidity entering the air washer undergoes a reduction in temperature of approximately 4.5 degrees. During the afternoon peak air entering the washer at 90 degrees and 62 percent relative humidity undergoes a reduction in temperature of approximately nine degrees. According to good authority, this amount of reduction in temperature corresponds to an increase in generator capacity of nine percent based on a given ultimate internal temperature.

In localities where the relative humidity is low, the temperature reduction will be even more marked. Air at 90 degrees and 10 percent relative humidity entering the washer would theoretically undergo a temperature reduction of 31 degrees, corresponding to an increase of generator capacity of at least 25 percent. These calculations are based on the assumption that the water for the spray is used over and over again. Where a continuous supply of cold well water is obtainable, the temperature reduction will be considerably greater.

The air cooling possibilities of conditioning apparatus are of considerable importance in plants where the generators are forced to operate up to rated capacity during the summer, and it may safely be stated that under certain conditions, the installation of an additional generating unit may be postponed for two or three years by the use of an air washing outfit.

The opinion seems to be current that the moisture gathered by the air in passing through the washer assists in cooling the generator. This is true to a limited extent. It can be shown that the heat capacity per degree of a saturated mixture of water vapor and air at a temperature of 90 degrees is only 1.5 per cent greater than the heat capacity per degree of perfectly dry air. This follows from the fact that seven pounds of air at this temperature can contain only slightly over two-tenths of a pound of moisture.

In conclusion it may be stated that the introduction of air conditioning apparatus in modern turbo-generator stations is a great step forward in efficient ventilation and should be vigorously advocated both by operators and manufacturers. Scientific attention to the quality as well as the quantity of cooling air will lead to results that will be very gratifying.

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The Function of Protective Relays

The increasing tendency towards refinements and perfection in the field of electrical power distribution is constantly presenting new problems, and among those of greatest general interest today is the problem of obtaining continuity of service. An infallible supply of power is becoming recognized as a matter of prime importance. In order to accomplish this end, transmission and distribution systems have become more complicated, provision being made for flow of power through a multiplicity of paths, so that in the event of failure in any one the supply may be continued through other channels. Such arrangements have necessitated the development of protective devices, circuit breakers and relays of improved types. In the case of circuit breakers, the development has been in the direction of controlling large amounts of power. In the relays, necessity has arisen for higher accuracy and reliability.

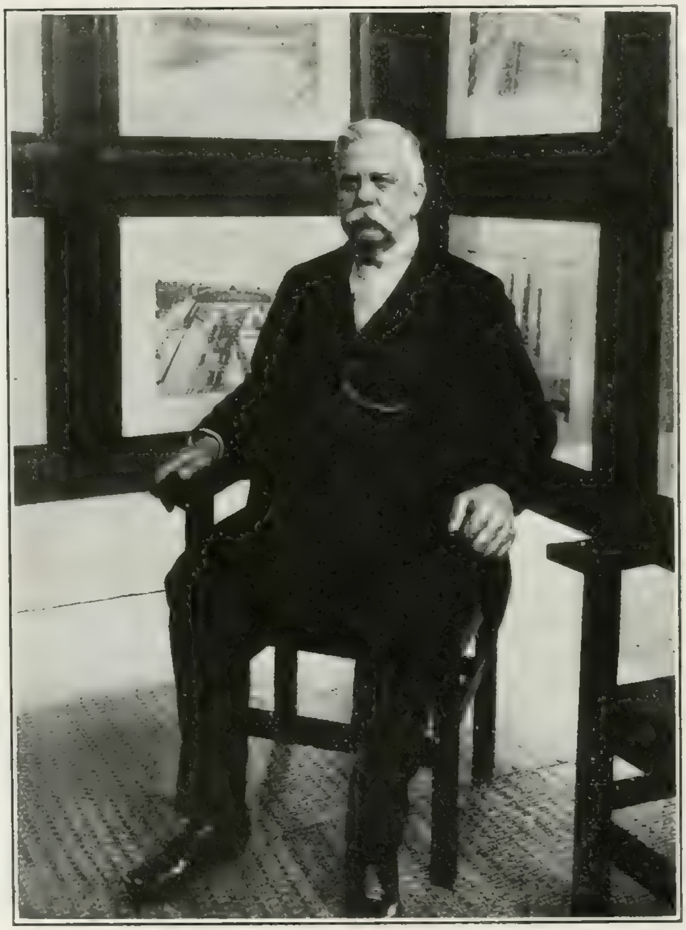
Originally the function of a protective relay was simply to trip out circuit breakers when direct acting trip coils could not be used, and they were considered principally from the point of view of protecting the apparatus operated through the circuit breaker. Protection of apparatus today is, however, of secondary importance to protection of continuity of service, and in consequence relays must insure a functioning of circuit breakers which will cause defective feeders or sections to be disconnected automatically without interruption of service. Thus, relays must not only be more reliable than formerly but their time elements, under all load conditions, must be capable of being exactly predetermined. Moreover, a very close study must be made of operating conditions, particularly as to the amounts of currents that will flow in the various branches, under assumed accidental conditions such as caused by short-circuits. With sufficient data of this sort at hand, and provided with relays having correct and reliable time element characteristics, much can be done to insure furnishing continuous service, as is admirably pointed out in the article by Mr. F. E. Ricketts in this issue of the JOURNAL.

P. M[illegible]

George Westinghouse

Born October 6, 1846 — Died March 12, 1914

THIS JOURNAL and its many readers manifestly share in the great loss caused by the passing away of Mr. George Westinghouse. The initial article in the first issue of the JOURNAL, in February, 1904, was a sketch of Mr. Westinghouse, accompanied by a full-page frontispiece. In the ten years that have followed, the editorial pages of the JOURNAL have been devoted to engineering subjects, following closely along the lines of greatest effort by the renowned inventor, and have included a number of contributions from him. Our location in Pittsburgh, the scene of the majority of Mr. Westinghouse' endeavors, has enabled our editors to maintain intimate contact with the numerous activities of the various companies in which he was interested.



Mr. Westinghouse possessed the rare faculty of great inventive genius, combined with the characteristics which enabled him to build up in forty-five years an aggregation of manufacturing industries employing some fifty thousand persons and two hundred million dollars capital. While endowed by inheritance with inventive instincts, his entrance into the business world was under comparatively humble circumstances, and his subsequent successes were undoubtedly due to his own perseverance and far-seeing judgment. Looking at his life in retrospect, as we now can, his foresight and persistence in the various lines of work to which he gave special attention mark him as one of the world's wisest inventors—engineers—manufacturers.

Mr. Westinghouse' life was characterized by an unusual versatility in engineering endeavor, embracing remarkable and far-reaching developments under four comprehensive headings, viz., Air, Gas, Steam and Electricity.

His conception of the air brake and his arrival in Pittsburgh occurred in the same year—1867. Two years later the Westinghouse Air Brake Company was formed. The early stories of his disheartening experiences in getting air brakes tried out by the railroads are well known. His success with the air brake in this country was followed by the introduction of the same system in Europe, which required a considerable portion of his time for a number of years. At one time the whole air brake scheme seemed about to be discredited when it came to applying air brakes to fifty car freight trains, in which case the use of the original air brake was both dangerous and destructive. Elaborate tests were made by a committee of the National Car Builders' Association and the air brake failed to meet the requirements. Mr. Westinghouse immediately set to work to remedy the difficulty. In a few months the quick action triple valve was invented and another set of tests was made, with results which were satisfactory to all concerned, and the tremendous growth of the Air Brake Company began. It has been characteristic of this company that notwithstanding their control of this business, they have been very active in perfecting the air brake and in keeping its development abreast of the times in the railroad world. To-day the air brake is recognized as one of the most vital factors in heavy high-speed railroad work, and only within the last few years tremendous strides have been made in applying air brakes to modern steel car equipments.

Having done so much work in the application of compressed air it was but natural that Mr. Westinghouse should consider the use of the same medium in solving other problems, and especially in the railroad field. Thus it came about that in 1879 he invented the pneumatic interlocking signaling system and in 1881 the Unicn Swith & Signal Company was organ-

ized. This Company has had a history somewhat similar to that of the Air Brake Company. It has been highly successful and has kept well to the forefront in the development of devices for signaling and interlocking on railroads. In more recent years this company has adopted ideas from the electrical field in which Mr. Westinghouse later became interested.

The most recent development in the use of air is the work now being carried on by the Westinghouse Air Spring Company at New Haven, Conn., which manufactures a device for absorbing vibration and shocks in the operation of automobiles. This device, while still very new, has already been adopted with success by a number of automobile manufacturers.

The discovery of natural gas in and around Pittsburgh also attracted the attention of Mr. Westinghouse, and he even had a well drilled on his own premises at "Solitude." The gas pressure, however, was so high as to make the use of gas in residences not only difficult but highly dangerous. With his usual versatility, he invented a pressure reducing system by which the use of gas was made entirely safe. This scheme was of great advantage to manufacturers of steel and glass. His interest in this subject resulted in the organization of what is now known as the Philadelphia Company, of which he was the first president. This company is now the public service corporation furnishing gas, electric light and power and street railway service to the Pittsburgh district. Mr. Westinghouse retired from this company in 1901. He was the inventor of a gas meter which had much to do with the conserving of the gas resources of the country, as the early use of gas was on the flat rate plan which was a very wasteful arrangement. He was the inventor of a complete system for transmitting gas from the wells through pipes to the users, and the system of gas pipes which brings gas from the West Virginia field was originated by him.

In 1880 The Westinghouse Machine Company was organized and was engaged for a number of years in the manufacture of steam and gas engines. It was the first company to engage in the manufacture of very large gas engines. In 1897-8 Mr. Westinghouse secured the patent rights of Mr. Charles A. Parsons, of England, on his steam turbine, and the Machine Company then became active in the development and manufacture of this prime mover. A great deal of development work was carried on under Mr. Westinghouse' personal supervision, and various forms of double flow, low pressure and mixed pressure types of turbines have been put on the market. Mr. Westinghouse also became interested in the application of steam turbines to marine work. The inherent high speed of the turbine stood in the way and, as a means of overcoming this disadvantage, he, in conection with the late Admiral Melville and his partner, John H. MacAlpine, developed the reduction gear which has since been applied not only in marine work but to central station service as well.

In 1886 he organized what proved to be his largest venture, the Westinghouse Electric Company, for the manufacture of lamps and lighting apparatus. This business developed rapidly, and in 1889-1890 the United States Electric Company and the Consolidated Electric Company were absorbed. In 1891 the company was reorganized and given its present name. In 1885 Mr. Westinghouse purchased the Gaulard & Gibbs patents for the alternating-current distribution of power. These inventions were the basis of the modern transformer and the alternating-current system. In 1887 he engaged Mr. Nikola Tesla, the discoverer of the rotating magnetic field and the inventor of the induction motor, and soon after began the development of these machines on a commercial scale. One of the spectacular features of the early history of the Electric Company was the obtaining in 1892 of the contract for the furnishing of the electrical equipment to the World's Fair at Chicago. Another epoch-making event was the building of the 5 000 horse-power, 25 cycle alternating-current turbine generators for the Niagara Falls Power Company in 1893. At that time these were the largest generators ever built, and they were of distinctly novel design. Mr. Westinghouse became the champion of the alternating-current system and the Electric Company has been pre-eminent in this field from the start. He was especially fortunate in securing the services of men who afterwards became prominent in the engineering field in developing various types of electrical apparatus, many of whom are still connected with the company and have attained national and international reputation in the engineering field. In 1886, when the Electric Company was organized, electric power was scarcely a factor in the world's business; today it is recognized as one of the most valuable servants of mankind.

In view of his work in the railway field it was inevitable that Mr. Westinghouse should become interested in the application of electricity to railways, and his company has been one of the leaders in the introduction of the various methods of electrical operation of railways, and in recent years has been especially active in steam railway electrification work.

To those who have not followed closely the varied activities of Mr. Westinghouse, an idea of the great extent of his interests may be obtained from a statement of the fact that he was president or a director of some thirty corporations of most of which he was the founder.

Owing to the revolutionary and far-reaching achievements accomplished by Mr. Westinghouse, his name has become known the world over, and in his later years many honors came to him from various institutions of learning and from technical societies both in this country and abroad.

Generator, Reactance and Circuit Breaker Performance Under Short-Circuit Conditions

F. D. NEWBURY—W. M. DANN—J. N. MAHONEY

FOREWORD—The tests described in the following article were made primarily to observe the behavior under actual short-circuit conditions, of current-limiting reactances designed for feeder circuits. It was originally suggested that the tests be carried out under actual operating conditions, but the operating company concerned could not isolate a suitable generating and feeder section of its system and the tests were accordingly made on the manufacturing company's test floor, using the most suitable apparatus available. That the conditions were, at least, as severe as if under actual operation, will be shown during the course of the article. When the tests had been outlined and arrangements made, a number of operating engineers were invited to witness them and from twenty-five to thirty engineers from many of the important Eastern steam and hydro-electric stations responded. After the completion of the tests they contributed to an interesting discussion of the results. The character of this discussion, from the standpoint of the generator and circuit breaker, as well as from that of the reactance, together with the keen interest shown by them, suggested the desirability of recording the test results and the discussion, for the benefit of a wider audience. This article has been prepared as such a report—admittedly fragmentary and incomplete, but justified by the original data and pertinent discussion it contains and the growing appreciation of the importance of the protection of service from interruption due to short-circuits.

THE GENERATOR used to produce the current in the tests herein described was a 15 000 k.v.a. three-phase, 60 cycle, 6 600 volt, 360 r.p.m. maximum rated water-wheel type generator. As will be shown from the oscillograms taken during the tests, the transient reactance* of the generator at 15 000 k.v.a., 6 600 volts, is 24 percent, resulting in a maximum possible short-circuit current of 7.5 times rated current. In order to increase this short-circuit current the generator voltage was increased in certain of the tests to 133 percent of normal, or 8 800 volts. With this voltage the transient reactance is 18 percent and the short-circuit current ten times rated current.

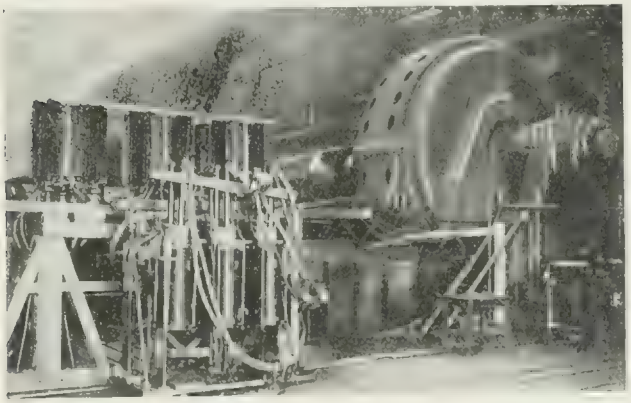


FIG. 1—GENERATOR, REACTANCES AND OIL SWITCH ASSEMBLED ON TESTING FLOOR

During the tests the generator was driven by a 500 kw direct-current motor. The relatively small size of this motor naturally led to the question of its effect on the short-circuit current due to a possible reduction in speed and voltage. In order to determine this effect, if any, a twenty-five cycle timing voltage wave from an independent source was recorded simultaneously with the sixty-cycle short-circuit current during the tests in which the effect would be a maximum, by which any variation from uniform rotation of the generator could be measured.

The armature winding of the generator was of the familiar two-coil-per-slot type, with V-shaped end connections, as shown in Fig. 2. The end connections were held against attraction to the core by a steel retaining ring supported in turn by iron brackets. They were held against mutual attraction and repulsion—by far the greatest stresses—by two rows of spacing blocks (one in each cylindrical surface of the end connections), as shown in this illustration.

THE REACTANCE COILS

The reactance coil, to test which these experiments were primarily made, was of the type shown in Fig. 3.* It was designed to carry a normal current of 200 amperes continuously. The average self-induction of the coils used, as measured by a separate set of tests, amounted to 0.0032 henries, or 1.21 ohms at 60 cycles. This represents 6.35 percent

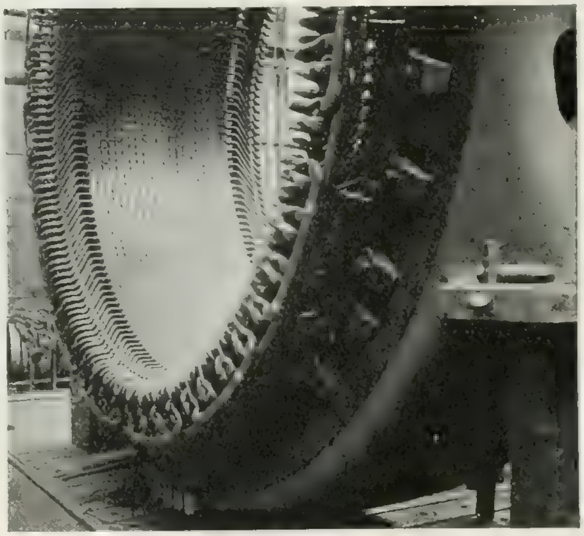


FIG. 2—WATER WHEEL GENERATOR ARMATURE WINDING AND COIL BRACING

*For the definition of this and other terms connected with short-circuit conditions used in this article, see article on "Generator Short-Circuit Waves" on pp. 196-200 of this issue.

*A full description of this type of current-limiting reactance appears on pp. 202-204 of this issue.

reactance in a 6 600 volt, three-phase feeder with a normal current of 200 amperes.

The stresses that have a tendency to cause physical displacement when heavy short-circuit currents flow through reactance coils, are the internal stresses affecting the parts of the coil itself, and the external mutual stresses that appear between adjacent coils or between a coil and adjacent magnetic material. The mutual effects between coils during these tests were neutralized by bolting wood braces across the tops of the coils in addition to fastening the feet to the floor of the platform.

Four reactance coils were provided for these tests in order that their behavior when grouped in an equilateral formation as well as in a straight line could easily be observed. The relative location of

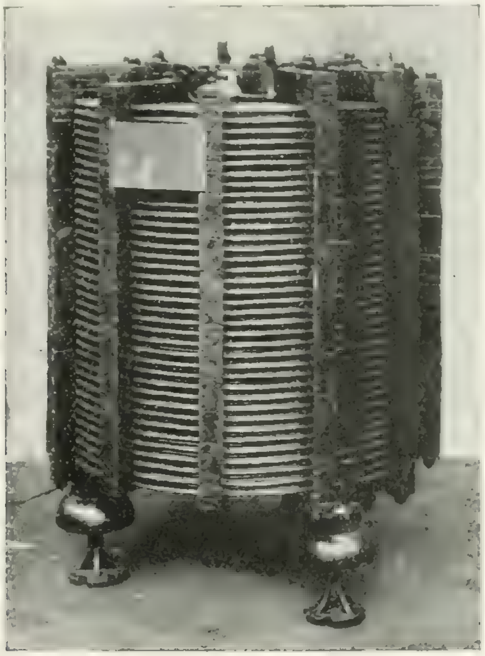


FIG. 3—TYPE OF REACTANCE COIL USED IN TESTS

the four coils is shown in Fig. 5. This diagram also shows the means used to switch quickly from one grouping to the other. For either formation, the distance between adjacent coils, measured from center to center, was 42 inches, or a minimum of 12 inches from conductor to conductor.

THE CIRCUIT BREAKER

The circuit breaker used, shown in Fig. 4, was a 3-pole, electrically operated, 300 ampere, 35 000 volt. oil switch of the pipe mounting type. It was arranged with alternating-current trip coils acting directly on the latch of the operating mechanism. The trip coils were supplied directly from the secondaries of current transformers without the use of any form of time element relay. This compelled the tripping of the breaker in the shortest practical time after the application of the short-circuit, as will be noted from the oscillograms. The operating mechanism was provided with an accelerating spring to assist gravity in initially and rapidly moving the contacts and with a dashpot to take up the shock of the moving parts at the end of the travel.

Construction—This circuit breaker has three single-pole metal frames which are clamped to the pipe supporting framework by U-bolts. The frame supports the porcelain terminal bushings and contact operating mechanism for each pole. The contacts on the moving element consist of a half-elliptical form of laminated brush having plunger type arcing contacts mounted just beyond the outer ends of the brush. The stationary contacts consist practically of flat blocks screwed on the ends of the terminal rods and have a removable arcing tip bolt engaging with the plunger arcing tip on the moving contact element. The tank which encloses the contacts is of elliptical shape, and is of the welded type. There is but one double lap welded seam, as the tank body is made from one sheet. The bottom is made in one piece, flanged over the side sheet and welded thereto. The tank is carried on a substantial flange casting, which is provided with appropriate fastenings for convenient attachment to the supporting frame. The oil level is several inches below the top of the tank in order to provide a chamber above the oil to take care

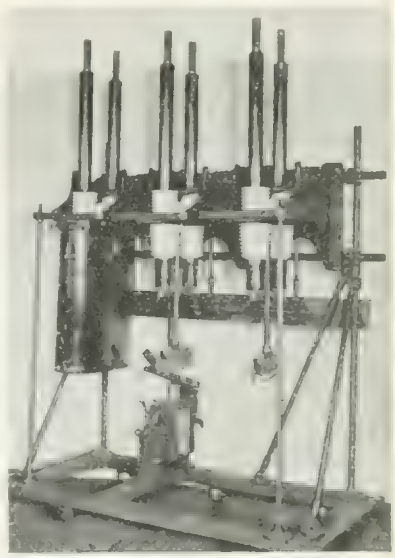


FIG. 4—[illegible] SWITCH [illegible] IN TESTS

of the disturbance in the oil under short-circuit conditions and to reduce the possible pressures resulting therefrom, and vent fittings are provided in the frame to allow the escape of the gases and retard the rejection of oil. The shape of the tank, which has practically no flat sides, permits it to withstand relatively high internal pressures without distortion.

THE TESTS

Short-circuit tests were made under the following conditions:—

a—On the generator alone at 6 600, 7 700 and 8 800 volts, all three phases being short-circuited simultaneously.

b—Three-phase short-circuits on the generator and reactance coils at 6 600 and 8 800 volts, the reactances being arranged, first, in a straight line and, second, in an equilateral triangle.

c—Single-phase short-circuits on the generator and reactance coils at 6 600 and 8 800 volts, using two coils, duplicating service conditions. Finally, to increase further the short-circuit current, the generator was short-circuited on one phase with a single reactance coil connected between phases.

The numerical results, obtained by measurement of the oscillograms, are shown in Tables I, II-a,

II-b and III, corresponding to test groups *a*, *b* and *c* as outlined. Typical oscillograms for these several test conditions are shown in Figs. 6 to 10, inclusive. That the results shown in the oscillograms are consistent will be evident from the following relations between the different quantities:—

In Table I, the short-circuit current I_{max} is substantially the same in the different phases and different tests for the same voltage; and substantially proportional to the voltage as shown by the values of reactance calculated from voltage and current.

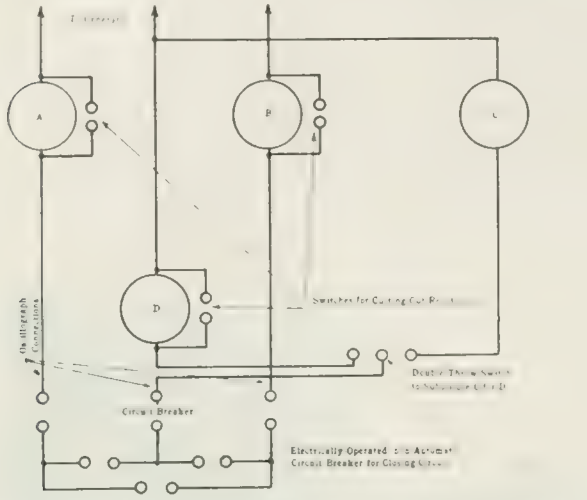


FIG. 5—DIAGRAM OF CONNECTIONS FOR SHORT-CIRCUIT TESTS

In Table II-a, the total reactance per phase of generator and coil, as calculated from the average oscillograph current and voltage values is 1.97 ohms. This checks closely with the sum of the reactance of the generator, determined from the oscillograph readings in Table I, (0.69 ohms) and the known reactance of one coil (1.21 ohms) or 1.90 ohms. By separate measurement, the reactance of the center coil (with the three coils arranged in a straight line) is 1.5 percent greater than that of the end coils, but this small difference is masked by the relatively greater error in the individual oscillogram measurements. For this reason the reactance of all coils has been considered the same in the above calculation. The reactance of a single coil, determined from the short-circuit current and the voltage measured across the coil also checks with its known reactance. The former value is 1.22 ohms as compared with the known value of 1.21 ohms. At the instant of short-circuit the generator terminal voltage drops to a value representing the drop across the reactances in lines *A* and *B*. The generator voltage after short-circuit recorded in the last column in Tables II-a, II-b and III is, in reality, the voltage across two reactance coils in three-phase relation. Therefore. the generator volts should be 1.73 times the voltage measured across a single coil. The oscillograph results show very closely that relation.

TABLE I—THREE PHASE GENERATOR SHORT-CIRCUITS WITHOUT REACTANCE

Osc. No.	Generator Voltage Effective	Phase	Maximum Current Values: 1st Alt.	2nd Alt.	I_1	I_2	I_{max}	Generator Reactance: Ohms per Phase	Percent
1	6600	A	4 100	10 900	15 000		14 500		
1	6600	B	0	14 100	14 100		14 100		
1	6600	C	11 200	4 350	15 550		15 000		
				Average.....			14 500	0.67	23
2	7700	A	12 800	5 600	18 400		17 500		
2	7700	B	2 970	13 100	16 070		15 700		
2	7700	C	0	15 600	15 600		15 600		
				Average.....			16 300	0.70	24
3	8800	A	14 500	7 100	21 600		20 500		
3	8800	C	0	17 500	17 500		17 500		
				Average......			19 000	0.69	24
							Average.. ...0.69 ohms.		

TABLE II-a—THREE-PHASE SHORT-CIRCUITS WITH REACTANCES IN A STRAIGHT LINE

Osc. No.	Generator Voltage Effective	Phase	Max. Current Values: 1st Alt.	2nd Alt.	I_1	I_2	I_{max}	Max. Voltage Values: React. Volts Single Coil	Generator
4	6600	A	5400	4000	4540		4470	3180	5650
4	6600	B	3650	1590	5240		5000	3270	
4	6600	C	1620	3300	4920		4670		
5	6600	A	4000	800	4800		4700	3250	
5	6600	B	1820	3400	5220		4950	3270	
5	6600	C	0	4900	4900		4900		
6	6600	A	800	4000	4800		4700	3270	5650
6	6600	B	4300	910	5210		5100	3270	
6	6600	C	2600	2400	5000		4550		
7	8800	A	4350	2450	6800		6400	4000	7150
7	8800	B	450	6400	6850		6800	4570	
7	8800	C	0	7200	7200		7200		
8	8800	A	5530	550	6080		6000	4250	7350
8	8800	B	2900	4300	7250		6750	4250	
8	8800	C	260	6400	6600		6630		
9	8800	A	4870	1740	6610		6400	4250	7600
9	8800	B	1160	5950	7110		7000	4450	
9	8800	C	0	7300	7300		7300		

In Table II-b, the current values should be slightly lower than the current values in Table II-a due to the greater mutual induction in coils *A* and *C* with the triangular arrangement, but the oscillogram measurements are not sufficiently accurate to show this difference. By separate measurement the mutual inductance of each coil is the same as that of the middle coil in the straight line arrangement. It will be seen that the values are substantially the same and the average is the same. As with the results in Table II-a values of reactance calculated from the oscillogram results check with the known values.

TABLE II-b—THREE PHASE SHORT-CIRCUITS WITH REACTANCES IN AN EQUILATERAL TRIANGLE

Osc. No.	Gen. V. Eff.	Phase	Max. Current Values: 1st Alt.	2nd Alt.	I_1	I_2	I_{max}	Max. Voltage Values: React. Volts Single Coil	Generator
10	8800	A	4350	2600	6950		6550	4100	7550
10	8800	B	600	6500	7100		7000	4700	
10	8800	C	0	7100	7100		7100		
11	8800	A	4000	2950	6950		6450	4100	7800
11	8800	B	300	6650	6950		6400	4800	
11	8800	C	0	7100	7100		7100		
12	8800	A	1040	5500	6540		6400	4500	7800
12	8800	B	4700	2460	7160		6800	4350	
12	8800	C	2550	4250	6200		6200		

In Table III, with a single-phase short-circuit and two reactance coils, as under actual operating conditions, the currents are lower than with a polyphase short-circuit due to the lower impressed voltage per coil. This ratio is 0.866. Using the average

current values from Tables II and III, the measured ratio is 0.885. The generator voltage after short-circuit is the arithmetical sum of the two coil voltages since the currents are in phase, which is borne out by the oscillograms. The combined reactance

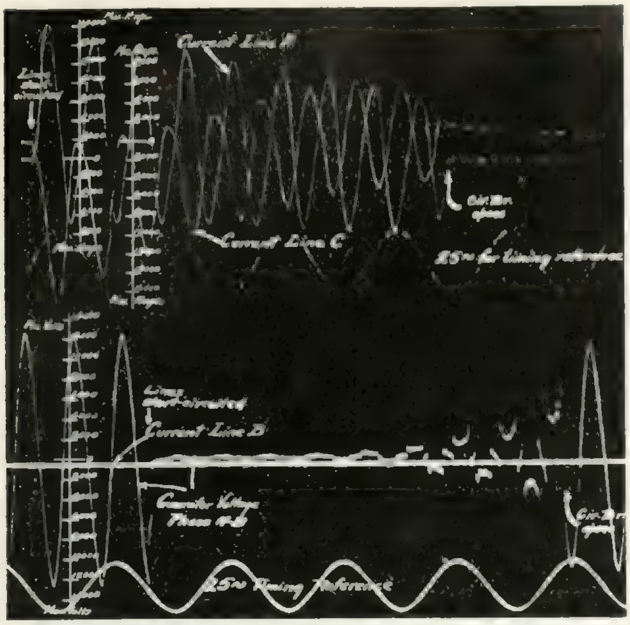


FIG. 6—OSCILLOGRAM 3, TABLE I, SHOWING THREE-PHASE SHORT-CIRCUIT

On generator alone at 133 percent normal voltage. Record taken on two separate, three element oscillographs showing generator voltage across phase *A-B*, current in phases *A* and *C* and a 25 cycle voltage wave from a separate source for timing purposes. Current in phase *B* shown as zero was incorrectly recorded due to some failure in connections of instrument transformer. Note voltage across circuit breaker terminals during opening period. See also Fig. 3, p. 197 for record of short-circuit on same generator at normal voltage.

calculated from the average currents and the generated voltage under the two single-phase conditions check very well with the known reactances of generator and coils. While the reactances of both generator and coils vary with polyphase and single-phase short-circuits, the difference is not large enough to be shown by the oscillogram measurements.

TABLE III SINGLE-PHASE SHORT-CIRCUITS WITH REACTANCE

Osc. No.	Generator Voltage Effective	No. Coils	Phase	Max. Current Values 1st Alt.	2nd Alt.	I_1	I	I_{max}	Max. Volt. values React Volts Single Coil	Generator
13	6600	2	A	3050	1220	4270	4000	2370	4900
13	6600	2	B	3200	1310	4510	4300	2550	
14	6600	2	A	4200	200	4400	4350	2820	[illegible]
14	6600	2	B	4350	300	4710	4650	2850	
15	6600	2	A	3700	1200	4400	1200	[illegible]	5150
15	6600	2	B	3400	1160	4560	4400	2600	
16	8800	2	A	4700	1400	6100	[illegible]	3500	7150
16	8800	2	B	4700	1500	6200	[illegible]	3600	
17	8800	2	A	5750	520	6270	6200	3600	7700
17	8800	2	B	5800	510	6310	6250	3800	
18	8800	2	A	1560	4350	5900	5700	[illegible]	[illegible]
18	8800	2	B	1650	4500	6100	[illegible]	3500	
19	8800	1	A	780	8300	9080	9000	[illegible]	[illegible]
19	8800	1	B	630	8200	8830	8800		

GENERATOR RESULTS

The most important question regarding the behavior of generators under short-circuit conditions is the ability of the armature coils to withstand the mechanical strains set up in them by the short-circuit current. That the winding structure in the generator under test is adequately strong, even with the increased stresses due to 133 percent of rated voltage, was conclusively shown by the absence even of an observable tremor during the most severe short-circuits and of any distortion after the thirty or more short-circuits required by the experiments had been made.

In considering the ability of generator windings to withstand short-circuit strains, two factors of equal importance must be kept in mind; first, the relative value of the short-circuit current producing the stresses on the winding; and, second, the strength of the winding structure opposed to these stresses It is obvious that these two factors must, at least, be properly proportioned, one to the other, if the generator can safely withstand short-circuits. That is,

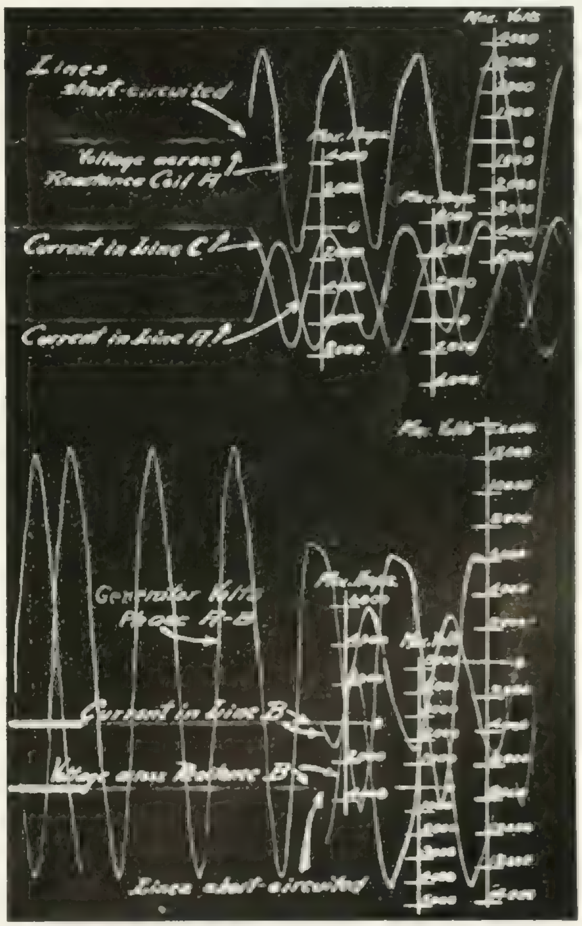


FIG. 7—OSCILLOGRAM 5, TABLE II-A, SHOWING THREE-PHASE SHORT-CIRCUIT ON GENERATOR AND REACTANCE AT 133 PERCENT NORMAL GENERATOR VOLTAGE

Reactances arranged in a straight line. Generator voltage measured between generator and reactance coils. Generator voltage after short-circuit equals reactive voltage across coils.

the larger the short-circuit current, the stronger the winding structure must be; and in turbo-generators sufficiently high reactance to obtain the lowest practicable short-circuit current is, in general, necessary to make the generator safe, even with the best forms

of coil bracing available. It does not necessarily follow that because a generator has a certain form of winding structure, or because it has a certain relative value of short-circuit current it will safely withstand the effects of short-circuit. Thus, in the water-wheel generator tested, a comparatively simple form of coil bracing is sufficient, due to the inherent rigidity of the short coil-ends and to the relatively small short-circuit currents involved. But in the largest two and four-pole turbo-generators with the much stronger coil bracing,* the factor of safety is actually smaller than in the water-wheel generator, due to the inherent weakness of the long coil-ends associated with two and four pole windings, and to the higher values of short-circuit current inherent in this type of generator. The modern type of turbo-generator coil bracing has been found adequate to withstand the stresses of short-circuits at the generator terminals at rated voltage in the largest two and four pole turbo-generators so far constructed, in which the maximum short-circuit currents have ranged from 15 to 25 times rated current.

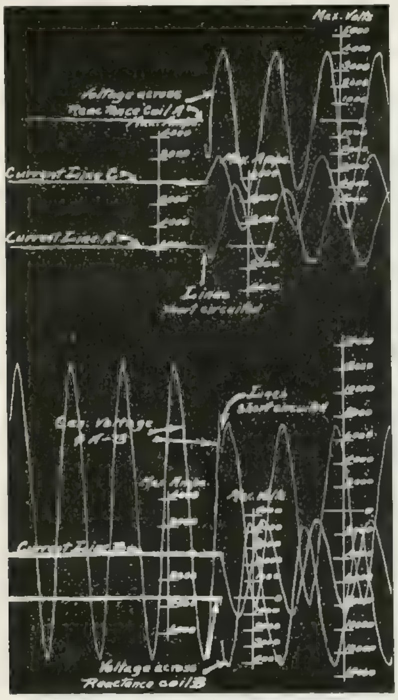


FIG. 8 OSCILLOGRAM 12, TABLE II-B, SHOWING THREE-PHASE SHORT-CIRCUIT ON GENERATOR AND REACTANCE AT 133 PERCENT NORMAL GENERATOR VOLTAGE

Same conditions as Fig. 7, except reactances arranged as an equilateral triangle.

It should also be borne in mind that the stresses between coils are different with polyphase and with single-phase short-circuits, between different coils in the winding, and with different initial instantaneous voltage values. The maximum stresses under any conditions occur in the case of a single-phase short-circuit and in adjacent coils of different phases, and when the short-circuit occurs at that point in the voltage wave resulting in the maximum possible current. The stresses are less in a polyphase short-circuit due to the fact that when the current is a maximum in one phase it is less than this maximum in the other phases.

The question of the ability of generator windings to withstand the more severe stresses sometimes involved in faulty synchronizing was raised during the discussion of these test results. Contrary to a somewhat general impression, these stresses are not always more severe than the short-circuit stresses. The resultant voltage causing current to circulate between the loaded generators and the incoming generator depends on the angle of phase difference between their voltages; and the current this resultant voltage sets up depends, in turn, on the combined reactance of the generators involved. With a single loaded generator on the busses and a duplicate incoming generator, the transient current due to wrong synchronizing can only equal the short-circuit current when the incoming generator is 180 degrees out of phase—it can never exceed the short-circuit current (assuming the reasonable condition that the voltages are the same in amount). While under this condition, the resultant voltage is double the generator voltage, and the reactance in the complete circuit is also double the reactance of one generator. With more than one loaded generator connected to the bus-bars, the combined reactance will be less than double that of a single generator and the transient current due to faulty synchronizing may be greater than the short-circuit current. But even with infinite generator capacity connected to the bus-bars the incoming generator would have to be 60 degrees out of phase before the resulting current in the incoming generator would equal its short-circuit current. With a variation from 2 to 10 loaded generators, this angle varies from 97 to 67 degrees, respectively. It is evident that with any ordinary errors by opera-

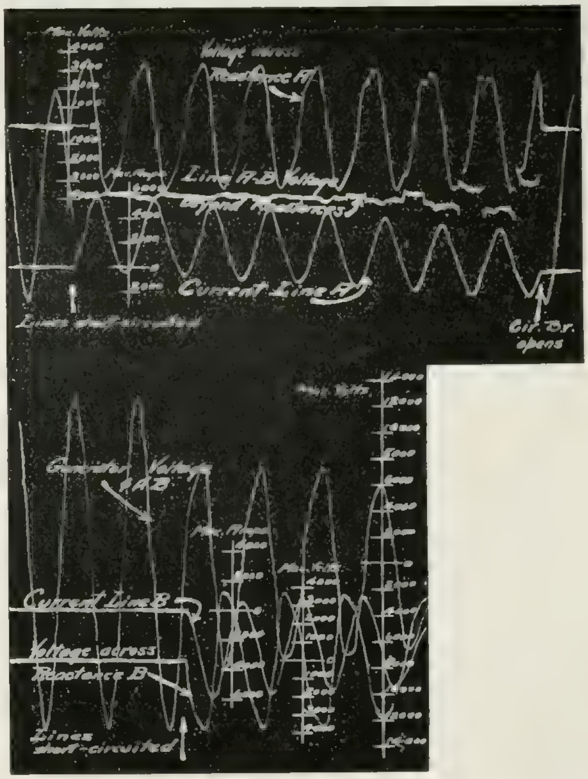


FIG. 9 OSCILLOGRAM 17, TABLE III, SHOWING SINGLE-PHASE SHORT-CIRCUIT ON GENERATOR AND REACTANCE AT 133 PERCENT NORMAL GENERATOR VOLTAGE

With two reactances in the short-circuited phases.

*See Figs. 3 and 4, p. 203, for illustration of this type of bracing.

tors in synchronizing, the resulting current and stress will be less than, rather than greater than, the current and stress due to short-circuit. However, it sometimes happens, due to wrong connections, or other extraordinary conditions, that generators are connected to the bus-bars directly out of phase, when stresses more severe than those of short- circuit will result. The ratio between the current in the incoming generator due to synchronizing 180 degrees out of phase and to short-circuit at rated voltage and the resulting ratio of stresses varies with the number of loaded generators, as indicated in Table IV. This comparison is based on similar generator connections in the case of short-circuit and in the case of wrong synchronizing; that is, a three-phase short-circuit is compared with three-phases simultaneously connected 180 degrees out of phase with the bus-bars, or a single-phase short-circuit is compared with a single-phase wrongly connected to the bus-bars. However, in operation, single-phase short-circuits are the rule and three-phase connections to the bus-bars are the rule; and this fact makes the comparison somewhat more favorable to the condition of wrong synchronizing than shown by Table IV.

TABLE IV.—RATIO OF CURRENTS AND STRESSES IN GENERATORS SHORT CIRCUITED AND INCORRECTLY SYNCHRONIZED.

No. of Loaded Generators	Ratio of Max. Current Values	Ratio of Max. Stresses
1	1.00	1.00
2	1.33	1.78
3	1.50	2.25
4	1.60	2.56
5	1.67	2.80
10	1.82	3.30

As the number of loaded generators becomes larger, the transient current in each loaded generator becomes proportionately smaller, so that the bus voltage is held more nearly to its initial value, and the decrease that does occur is less rapid than in the case of short-circuit. The only effect of this, however, aside from the above increase in maximum current, is to maintain successive peaks of current nearer the initial peak value, but this is of little importance, practically, as any serious distortion is done by the first maximum half wave of current.

It will be seen, therefore, that the ability of a generator to withstand safely the stresses set up by wrong synchronizing depends largely on the number and transient reactance of the generators with which it must operate in parallel, and the likelihood of connecting the generator to the bus-bars directly out of phase. While many generators under their conditions of operation will, undoubtedly, withstand such stresses without injury, it is equally certain that some will not. But the importance of this question from the standpoint of generator design, is minimized by the fact that the generators can be easily protected against stresses due to wrong synchronizing without any counterbalancing sacrifice in continuity of service. This may be done by connecting each generator to the bus-bars through a suitable reactance, the reactance being immediately thereafter short-circuited. This reactance may be small, since it will be in circuit for a few seconds only. This arrangement is simply an application of the familiar reactance-type circuit breaker.

There are two conditions usually existing in a factory short-circuit test that differ widely from the conditions of actual operation, the effect of which on the value of the short-circuit current may be reasonably questioned. These are the use of a relatively small driving motor for the generator under test, and short-circuit without load on the generator, necessitating relatively low values of field current.

It is a matter of ordinary observation that in making short-circuit tests the driving belt does not indicate any sudden increase in torque at the instant of short-circuit. If such an increase occurred, it would result in a sudden reduction in speed and slippage of the belt, the effect of which would be obvious and possibly spectacular. The result of this general observation is confirmed by the oscillograph record in Fig. 6. If the twenty-five cycle timing wave is used to lay off a horizontal time scale on the oscillogram, it is found that the time between peaks of the short-circuit current wave is constant at 0.017 seconds, as nearly as it can be measured, throughout the nine cycles representing the time between the instant of short-circuit and the complete opening of the circuit by the circuit breaker. This means that even with full power back of the generator the speed and voltage could not have been maintained any better and the short-circuit current wave would not have been any different. This result is entirely reasonable in the light of the amount of power involved in the short-circuit. From the standpoint of speed changes, the average torque is of importance, and from the shape of the current wave it is evident that this is small even with very large maximum instantaneous values. From the standpoint of possible damage to the machine structure, the instantaneous values of torque are the important values. Short-circuits have occurred in regular operation in which shafts have been bent or spiders cracked or—as happened with a vertical water-wheel driven generator—the entire stator shifted on the foundation. Such evidences of extremely large instanteous torques between stator and rotor have only been found when the reactance is extremely low and the short-circuit current correspondingly high.*

A little consideration will show that the low field current necessitated by the conditions of a shop test can have little effect on the value of the short-circuit current. The latter is determined by the flux

*These conclusions in regard to the absence of speed change during short-circuit are confirmed by the tests made by Schuchardt and Schweitzer published in Vol. XXX of the Transactions of the American Institute of Electrical Engineers.

and resulting voltage. While field currents are necessarily larger when the generator is carrying load, the increase is balanced by the demagnetizing effect of the armature current, and the net flux and generated voltage is practically the same as with no load.

CIRCUIT BREAKER RESULTS

The breaking capacity rating of the circuit breaker under test is 25 000 k.v.a. at its normal voltage of 35 000 volts. On the basis of rating as used by the manufacturer* this means that the circuit breaker is capable of rupturing kilovolt-amperes equal to one-half the maximum initial short-circuit current of 25 000 k.v.a. of 35 000 volt apparatus. On this basis of rating the breaking capacity rating is increased one percent for every one percent decrease in the voltage across the circuit breaker below its normal rating. These figures would indicate that at 8 800 volts the circuit breaker should rupture a short-circuit of approximately 18 000 amperes per phase, three-phase.

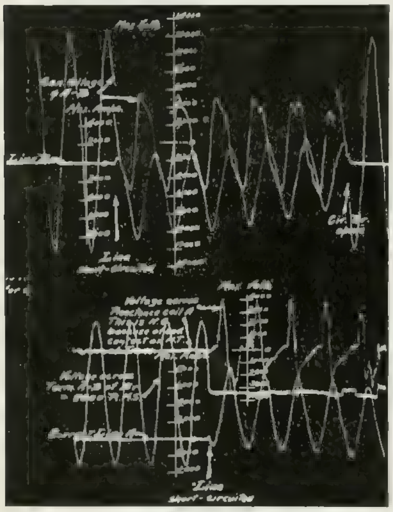


FIG. 10—OSCILLOGRAM *19*, TABLE III, SHOWING SINGLE-PHASE SHORT-CIRCUIT ON GENERATOR AND REACTANCE AT 133 PERCENT NORMAL GENERATOR VOLTAGE
With one reactance in short-circuited phase.

This basis of rating assumes that no transient conditions exist other than the dynamic flow of current into the short-circuit, and that any disturbances caused by the short-circuit condition will be absorbed by the operating system or load. This is the normal condition of operating practice wherein one or more generators supply numerous feeders in an ordinary distribution. Under the conditions of this particular test it will be noted that the entire capacity was concentrated through one circuit breaker and one circuit to the point of short-circuit. Under these conditions, the circuit breaker is compelled to absorb the stored magnetic energy of the circuit in addition to rupturing the short-circuit current. In the usual system the generator circuit breakers are usually non-automatic and the feeder circuit breakers are automatic. The feeder is usually one of many and when the circuit breaker opens, it clears the short-circuit current flow without the necessity of absorbing the magnetic energy of the circuit, because this is dissipated in the load on the parallel feeders. Also the trip devices used in ordinary practice usually have a time element feature which retards the opening of the circuit breaker until the short-circuit current has been reduced. This is essential in practice in order to prevent the feeder circuit breakers from tripping on overloads on the system that should be taken care of by other breakers near the point of trouble.

Reference to Fig. 6 will show that the current values were nearly equal to 18 000 amperes. Fig. 6 shows that the contacts parted and caused an arc voltage to appear on the oscillogram at approximately the fifth cycle or one-twelfth of a second after the lines were short-circuited. The arc persisted in the oil for approximately five cycles, and transient voltages which were evident during this arcing period, greatly exceeded the generator voltage, and in fact were at such frequency and amplitude as to be partly unrecordable on the oscillogram. These effects are wholly attributable to the stored magnetic energy in the circuit, producing oscillatory voltages which repeatedly broke down the oil insulation between contacts until dissipated.

It will be noted that the amplitude of the arc voltage wave increased with each succeeding cycle and reduced the current proportionately in the successive cycle until this part of the work imposed on the circuit breaker was reduced to a controllable amount. This factor very greatly increases the work done by the circuit breaker, inasmuch as the persistent arcing during this period causes the generation of a considerable gas pressure which would wreck any apparatus that did not contemplate this effect in the initial design

It is usual to expect the arc to persist but one or two cycles under normal operating conditions, depending on the rapidity of movement of the contacts in oil, and the generator voltage. Comparisons with Fig. 6 are shown in Fig. 11 (and in Fig. 5, p. 198), having nearly the same value of current and voltage as shown in Fig. 6, but in which the arc persisted for one-half cycle only in the circuit breaker. Fig. 5, p. 198, shows the short-circuit characteristic of the 8 000 volt, 25 cycle circuit on the particular test. Fig. 11 shows the voltage waves taken from voltage transformers connected in star across the circuit breaker contacts when opening the short-circuit current shown in Fig. 5. It will be noted that the short-circuit was cleared on the third cycle with an entire absence of any transient effects during the arcing stage. The circuit breaker used in this instance was rated at one-half the rupturing capacity of that used in the tests under discussion, and it is apparent from the oscillograms that the work imposed on it was very much less than that indicated in Fig. 6, notwithstanding the larger current.

The above data is presented to assist in comparing the data shown, with what may be expected in practice. As stated in the foregoing paragraphs, the generator used in the tests was a 15 000 k.v.a. ma-

*See article on "Breaking Capacity Rating of Oil Circuit Breakers" in the JOURNAL for Nov., 1913.

chine at 6600 volts. In these particular tests it was operated at 8800 volts, giving it a temporary rating of approximately 20000 k.v.a. Under this condition it gave a short circuit current one-third greater than at its normal rated voltage. As far as the circuit breaker is concerned the duty is 1.33^2 or 1.77 times as severe as with 15000 k.v.a. of 6600 volt apparatus (or approximately 26000 k.v.a.). This is so, since the duty on the circuit breaker is the result of voltage and current. This fact, together with the method of instantaneous tripping used during the test and the entire absence of any other load on the machine, produced conditions, as far as the circuit-breaker is concerned, that are approximately equal to a short-circuit on a plant of like characteristics of twice the capacity above mentioned, or approximately 50000 k.v.a. It is therefore seen that these tests, as far as the circuit-breaker is concerned, rank in importance with any made.

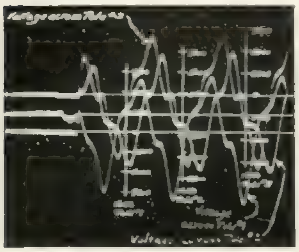


FIG. 11—VOLTAGE ACROSS THE CIRCUIT BREAKER TERMINALS IN OPENING A SHORT-CIRCUIT ON A 25 CYCLE TURBO-GENERATOR

REACTANCE COIL RESULTS

The reactance coils were found to be unaffected by the numerous short-circuits that were formed. A searching investigation after the short-circuits failed to bring to light any evidence of movement either of the coils as a whole or of the conductors of the coils.

A direct comparison between the stresses developed during these tests and those that could occur on a large system, would be difficult to present if made over the whole period of time required by the circuit breakers to relieve the short-circuit. This comparison would involve the time constants of the circuits, which would govern the rates at which displaced waves would return to the position of symmetry around the normal axis, and the armature reactions of the generators which would be the cause of a decrease in amplitude of successive waves through the gradual loss of generator voltage. The worst mechanical stresses in the circuit occur, however, in the first cycle.

Among the many short-circuits made during the tests there are several which occurred at such a point in the voltage wave that one of the current waves was displaced almost entirely on one side of the normal axis. Fig. 12 shows the three line currents from the oscillograms of Fig. 7 grouped together in time relation as accurately as the process of transferring from film to sketch will allow. This represents a three-phase short-circuit with the generator excited to 8800 volts and one reactance in each lead. It is an example of approximately the worst conditions of internal stress that can exist in a reactance coil at the time of short-circuit. The mutual stresses between reactance coils *B* and *C* will be proportional to the product of the ordinates of the current waves in those two lines. While there can be a combination of current waves obtained in a short-circuit occurring at some other instant which would produce a somewhat greater mutual stress between coils, it is evident from the curves that the mutual stress is very close to the maximum possible.

The displacement of the axis of symmetry of the current curve *C* at the ordinate of the maximum point of the wave has been labeled 100. The intersection of this axis of symmetry with the ordinate at the time when the short-circuit was closed represents one-half the ordinate of the maximum theoretical current that could possibly flow through the impedance of the circuit with the voltage that was present just before the short-circuit. To the scale of the ordinate labeled 100, this maximum ordinate measures approximately 105.

This small difference between the recorded ordinate and the absolute limit of current that could flow, makes it justifiable to neglect all considerations of time-constant of the circuit and drop of generator voltage due to armature reaction. For any other conditions of voltage and impedance the current then becomes proportional to the voltage and inversely proportional to the total impedance of the circuit, assuming the short-circuit to occur at the same instant with respect to the voltage wave. This makes possible a comparison between the actual tests and similar conditions in a large generating station.

For such a comparison, assume a station having four of the 15000 k.v.a. generators used in the tests, operating at 6600 volts. Assume this 60000 k.v.a. of normal capacity to be concentrated on a 200 ampere feeder having one of the 6.35 percent reactances in each leg and a three-phase short-circuit just beyond the reactances. The total impedance per phase of this system would be 1.38 ohms in comparison with 1.90 ohms with one generator. In terms of the maximum current of the first cycle in Fig. 12, the maximum current of the assumed system would be $\frac{6600}{8800}\times\frac{1.9}{1.38} = 103$ percent of that in the test.

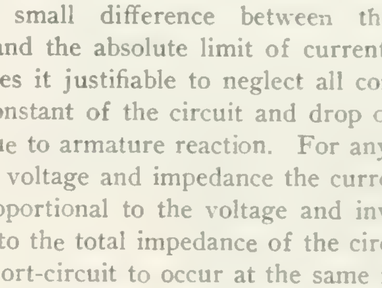


FIG. 12—OSCILLOGRAPHIC CURVES SHOWING RELATION OF THE THREE LINE CURRENTS UNDER SHORT-CIRCUIT AS SHOWN SEPARATELY IN FIG. 7

For the worst conditions then that could be brought about in this assumed system, as regards instant of short-circuit and displacement of current waves, the mechanical stresses would be roughly the same as in the actual tests. Considering the many

chances of short-circuits occurring under less severe conditions in point of time and wave displacement, these tests are considered to be quite comparable in severity to the ordinary short-circuits in actual operation in a fairly large system.

For a generating system so large that the bus-bar voltage could be assumed constant, the mechanical stresses affecting the reactance coils would be roughly 50 percent greater than in the actual tests.

The single-phase short-circuits, the results of which are shown typically in Fig. 9, show somewhat smaller currents than in the three-phase short-circuits, which is to be expected. The internal stresses are on that account less than in the three-phase short-circuit. The mutual stresses between coils *A* and *B* are more nearly comparable to the mutual stresses between *B* and *C* in the three-phase short-circuit of Figs. 7 and 12, however, since the current in the two coils are almost exactly in phase.

Fig. 10 shows the current with the 15 000 k.v.a. generator excited to the 33 percent over-voltage and short-circuited with only one reactance coil across one phase, and Table III shows that the maximum current was recorded as about 9 000 amperes. In the three-phase short-circuit of Fig. 7 the maximum current was about 7 000 amperes. The internal stresses in the reactance coil were therefore something over 60 percent greater than in the three-phase short-circuit and this makes them comparable to the maximum stresses that could be developed in a 6 600 volt generating station of infinite capacity.

In review, the study of the curves and test data brings out the facts that the internal stresses in the reactance coils and the mutual stresses between coils were of the order to be expected in the ordinary 6 600 volt system of, say 50 000 k.v.a. capacity, and roughly comparable to two-thirds of the maximum stresses which could occur in a 6 600 volt system of infinite generator capacity; and that the internal stresses in the reactance coil during the last test with one reactance coil alone were of the order to be expected in a 6 600 volt system of infinite generator capacity.

Generator Short-Circuit Current Waves

F. D. Newbury

FOREWORD—The practical importance of observations of generator short-circuits and the present confusion, both in published articles and in engineering specifications, as to the meaning of various terms relating to short-circuit conditions, make it worth while to examine some of the properties of the short-circuit current wave with the hope that some of these ambiguities may be removed. The present article will discuss some of the more important characteristics of the theoretical short-circuit current wave, describe two methods of approximating the maximum possible short-circuit current from an oscillograph record, and define reactance and short-circuit current as applied to short-circuit conditions.

The first rush of current after short-circuit is determined by the generated voltage at the instant of short-circuit and by the combined reactance of the various stator and rotor circuits involved. The effect of resistance may be neglected except for its effect on the rate of decrement of the short-circuit wave.

The generated voltage continuously decreases during the transient period due to the increasing demagnetizing effect, on the main flux, of the flux set up by the armature current. In fact, the initial flux is practically destroyed before stable conditions are reached. While the armature current, and the flux set up by it, are continuously decreasing, the effect of this flux on the main flux is continuously increasing, during the transient period, due to the relatively long time required to effect any change in the main flux. Due principally to this cause, the instantaneous short-circuit current is, in large high speed generators, from 10 to 20 times the steady short-circuit current for equal field currents. It is perhaps more usual to consider the generated voltage constant and the decrease in current to be due to an increase in apparent reactance (caused by armature demagnetization). However, the armature flux reduces the main flux directly and the voltage corresponding to the original value of main flux is not actually generated, after the armature flux becomes effective, so that the conception of variable voltage is more closely in accord with the physical facts and assists in forming a mental picture of the true sequence of events during short-circuit.

The reactance is a somewhat variable and highly complex quantity, being determined not only by the true self-induction of the phase, or phases, short-circuited, but by the mutual induction between phases carrying current, and between the field and armature windings (including any closed rotor circuits, such as solid poles or cage damper windings in which currents may be induced). This equivalent reactance is different when three phases are simultaneously short-circuited than when only part of the winding is short-circuited. It is obviously different from the reactance due to the self-induction of the armature winding effective during synchronous operation under steady current conditions. It is convenient to call this equivalent reactance existing during the short-circuit period the *"transient reactance"* of the generator. In this article a polyphase short-circuit of the entire winding will be assumed.

For convenience in analysis and explanation, the generated voltage may be assumed constant at the value existing at the instant prior to short-circuit. This introduces no serious error in connection with the first few alternations, but for longer intervals of time the rapid decrease in voltage must be kept in mind.

The transient reactance may also be assumed constant. Under these assumed conditions of constant voltage and reactance, the current conditions will be the same as in any simple circuit containing reactance and resistance to which a steady alternating voltage is suddenly applied. Typical current curves under these conditions are shown in Figs. 1 and 2.* These curves differ only in the initial value of the voltage at the instant of short-circuit.

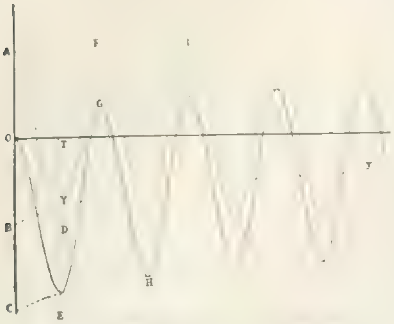


FIG. 1—CONVENTIONAL SHORT-CIRCUIT WAVE WITH MAXIMUM DISPLACEMENT

The ordinates of the resultant current curve *OEG* are the sums of the ordinates of the two component curves *BX* and *ADF*. The former component is the familiar logarithmic function representing the storage of energy in the magnetic field due to the current, and for convenience will be called the logarithmic component. The latter component is a sine function and is equal to the final steady value, in amplitude and phase, of the alternating current under the assumptions of constant voltage and reactance. Similarly, this will be called the sine component. In the generator, both components steadily decrease in value below those shown in the curves because of the decrease in generated voltage. It is obvious that the logarithmic component is coincident with the axis of symmetry of the resultant curve and the displacement of this axis of symmetry from the zero current line is equal to the logarithmic component.

It is a familiar characteristic of short-circuit waves that the first two half waves may be equal in amplitude, or one may be zero, as in Fig. 1, or their ratio may have any value between these extremes. These variations are due to the accidental variation, in different short-circuits, in the instantaneous value of the voltage wave at the instant of short-circuit. These conditions and the reasons for them may be explained by reference to Figs. 1 and 2.

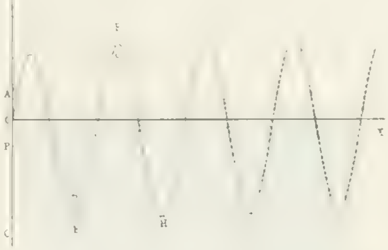


FIG. 2—SHORT-CIRCUIT WAVE WITH ONE-THIRD MAXIMUM DISPLACEMENT

At the instant of short-circuit, the logarithmic and sine components are equal in value and opposite in sign. This necessarily follows from the fact that the resultant current is zero. The logarithmic component will have its maximum initial value and, consequently, the resultant current wave will have its maximum displacement from the zero axis when the initial value of the sine component is a maximum; that is when the short-circuit occurs at that point in the voltage wave corresponding to maximum current under steady conditions. Since the power-factor of the short-circuit current is practically zero (probably less than 10 percent in all cases) maximum current corresponds approximately with zero voltage. The resultant current wave will be displaced in the negative direction when the voltage wave is decreasing from zero and in the positive direction when the voltage wave is increasing from zero. Conversely, the logarithmic component will be zero and the short-circuit wave will be symmetrical with respect to the zero current line when the short-circuit occurs at that point in the voltage wave corresponding to zero current under steady conditions. In Fig. 1 the circuit was closed at a point corresponding to maximum steady current (and approximately zero voltage), and in Fig. 2 the circuit was closed at an intermediate current value approximately one-third its maximum under steady conditions. In this connection it is interesting to note that in a three-phase short-circuit the instantaneous values of the voltages are obviously different in the three-phases at the instant of short-circuit and, consequently, the peak values of the currents in the three-phases will be different. If we assume that the voltage in one phase is such as to result in maximum short-circuit current in that phase, the currents in the two other phases will be displaced half as much in the opposite direction and the maximum peak values will be 75 percent of the maximum peak value of the first phase. Furthermore, since one voltage wave will be increasing and the other decreasing in value, the current waves will be opposite in sign during the first alternation after short-circuit. These relations, which have an important bearing on the mechanical stresses between armature coils during short-circuit, are illustrated by the currents in the three phases in Fig. 3.

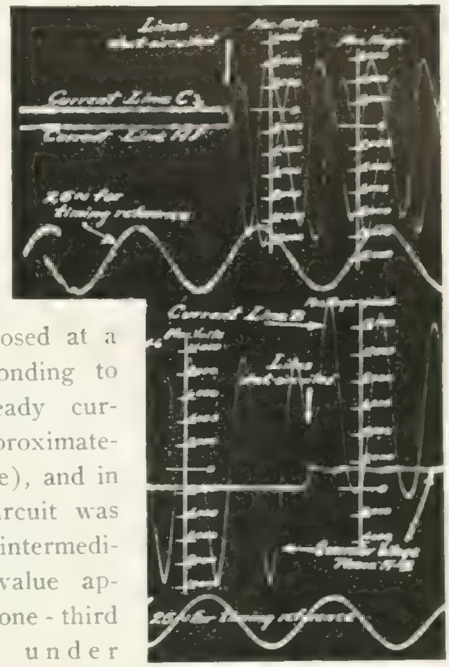


FIG. 3—OSCILLOGRAM [illegible] TABLE I (OF PREVIOUS ARTICLE) SHOWING THREE-PHASE SHORT-CIRCUIT AT NORMAL [illegible] WHEEL GENERATOR

Record taken [illegible] separate three-element oscillographs showing generator voltage, current in phases *A*, *B* and *C*, and 25 cycle voltage wave from separate sources for timing purposes.

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*For the equations and analytical discussion of these curves, see Bedell & Crehore "Alternating Currents'," fourth edition, pp. 50 59.

When the logarithmic component has its maximum initial value, the peak value of the short-circuit current has its *maximum instantaneous value*, and when the logarithmic component is zero the short-circuit current has its minimum possible value. Since the initial values of the two components are equal, the *maximum possible instantaneous value* of the short-circuit current is approximately double the minimum possible value and the sine component. It is somewhat less than double due to the decrease in ordinate of the logarithmic component DY in the time OT (Fig. 1), and to the further decrease in both components due to decrease in generated voltage (not shown in Fig. 1). If ambiguity is to be avoided references to short-circuit current should clearly distinguish between maximum and minimum possible current.

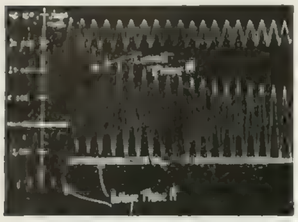

FIG. 4—THREE-PHASE SHORT-CIRCUIT FOR NORMAL VOLTAGE ON A LARGE 60 CYCLE TURBO-GENERATOR

Middle and lower records show generator voltage and current in one phase. Upper record is a voltage induced in a special exploring coil which may be neglected.

In making short-circuit tests it is by no means certain that the current in any of the phases will even approximate the maximum possible short-circuit current. It is convenient, therefore, to have available some method of readily calculating this maximum possible current from the oscillograph record of any single test. The preceding general characteristics of the short-circuit wave suggest two sufficiently accurate and convenient methods. The sum of the maximum ordinates of the first two alternations are approximately equal to the desired peak value. The variation in the methods consists in the correction applied to the sum of these peak values.

a—The maximum ordinates of the first two alternations may be added graphically on the oscillogram by extending a curve adjoining several maximum positive and negative ordinates back to the ordinate representing the instant of short circuit. In Fig. 1 such curves are HEC and JGO. This total ordinate represents the theoretically maximum short-circuit current at zero time, an approximate correction being included for variations in voltage and reactance. From measurements of a large number of oscillograms representing both water wheel and turbo-generators, it has been found that the change in voltage and reactance and the decrease in total current due to decrease in the logarithmic component is sufficient to make, as an average value,—

$$I_{max.} = 0.9 I_o$$

In which $I_{max.}$ = maximum peak value of short-circuit current that actually can occur. (TE in Fig. 1).

I_o = theoretical maximum peak value of short-circuit current at zero time (OC in Fig. 1).

It should be understood that this relation between I_o and $I_{max.}$ is only roughly approximate and varies with every generator and every change in external reactance if such coils are used. It depends on the time constant ($L \div R$) of the circuit, the value of the short-circuit current and the rate at which the generator flux can be changed.

b—The correcting factor applied to the sum of the peak values of the first two half waves depends on the length of time elapsing before their completion. This time will vary, due to the varying time of the first half wave. The ratio of the peak values of the first two half waves is a convenient and sufficiently accurate measure of this time. When the oscillogram shows directly the maximum possible peak value, the zero value of current at zero time is to be used as this value for the first half wave. Using this method of correction the maximum possible short-circuit current may be calculated by means of the following approximate formula:—

$$I_{max.} = (I_1 + I_2)\left(1 - 0.1\frac{I_2}{I_1}\right)$$

In which I_1 and I_2 are the maximum ordinates of the first and second consecutive half waves; I_1 representing the larger and I_2 the smaller without regard to precedence in the oscillogram.

Figs. 3, 4 and 5 represent three-phase short-circuits on three different generators of the different types of importance in connection with short-circuit phenomena. Fig. 3 shows the current in all three phases at normal voltage in a 15 000 k.v.a., 60 cycle, three-phase water wheel generator. The current in phase B happens to be the maximum possible short-circuit current, the current wave being displaced a maximum in the positive direction. The other phases necessarily show smaller and approximately equal displacements in the negative direction. Fig. 4 represents a three-phase short-circuit at rated voltage on a large 60 cycle turbo-generator but shows the current in only one phase. Fig. 5 represents a three-phase short-circuit at 60 percent rated voltage on a large 25 cycle turbo-generator, the current in all phases being shown. As in Fig. 3, one phase has approximately the maximum possible short-circuit current.

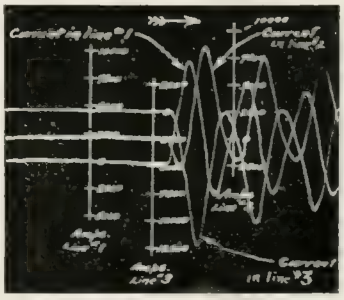

FIG. 5—THREE-PHASE SHORT-CIRCUIT AT 60 PERCENT NORMAL VOLTAGE ON LARGE 25 CYCLE TURBO-GENERATOR

The various current values from these oscillograms and from other oscillograms taken under similar conditions from the same machines are given in Table I. The table shows directly the close agreement between values of $I_{max.}$ calculated according to the two methods described.

The value of the sine component of the short-circuit current is determined by the same factors—

voltage, resistance and reactance—and in the same simple relation as the final steady alternating current. This leads directly to the rational definition of transient reactance and a convenient method for its approximate determination.* The *transient reactance* is the maximum value of the voltage, at the instant before short-circuit, divided by the corresponding maximum ordinate of the *sine component* of the short-circuit current; or from relations already explained:—

$$\text{Transient reactance (ohms)} = \frac{2\,E}{I_o} = \frac{1.8\,E}{I_{max}}$$

The transient reactance is, in most cases, expressed as a percentage:—that is the ratio of the reactive voltage at rated current to the rated voltage. From these definitions it follows that the ratio of maximum short-circuit current I_{max}. to the rated current (comparing peak values) is 180 divided by the percentage reactance, or;

$$\frac{I_{max.}}{I_r} = \frac{180}{\%\ \text{reactance}}$$

From these relations and the voltage and current values given in Table I the reactance and short-circuit current ratio of the three generators at rated current and voltage have been determined as follows:—

Generator	Percent Reactance	$\frac{I_{max}}{I_r}$
1—Large 60 cycle water wheel	24	7.5
2—Large 60 cycle turbo........	7.4	24.3
3—Large 25 cycle turbo........	10.9	16.5

It should be pointed out that the large 60 cycle turbo-generator does not fairly represent its class from the standpoint of reactance. Special mechanical and electrical requirements in this particular case necessitated a relatively weak armature, magnetically, as compared with the field with consequent low reactance. A typical 60 cycle turbo-generator of from 15 000 to 25 000 k.v.a. at 1 800 r.p.m. would have approximately double this reactance. The 60 cycle water wheel generator and the 25 cycle turbo generator reactance are fairly representative of these classes.

As a rougher approximation, the theoretical maximum current I_o and the actual maximum current I_{max}. may be considered identical, when

$$\frac{I_{max.}}{I_r} = \frac{200}{\%\ \text{reactance}}$$

There is no justification in spite of its frequent use for the simple relation,

$$\frac{I_{max.}}{I_r} = \frac{100}{\%\ \text{reactance}}$$

This involves the obviously incorrect assumption that the short-circuit wave will always be symmetrical and therefore equivalent to the sine component.

It is, of course, possible to consider effective values of the short-circuit wave instead of instantaneous maximum values but the effect of the short-circuit current that is of practical importance is the instantaneous value of the mechanical stress produced, and from this standpoint instantaneous maximum values of current rather than any other, are of consequence. Moreover, maximum instantaneous values are more convenient to use as they are easily measured on oscillograms and the maximum value of the rated current is readily calculated.

The maximum possible short-circuit current is of greater practical importance than any other lower value since the maximum stresses between coils are produced when the product of the instantaneous current values in the two phases are a maximum. Specifically, the maximum possible stress is produced when two lines are short-circuited, producing a single-phase short-circuit in two phases of the winding, and when the maximum possible short-circuit current occurs.

These same relations between voltage, reactance

TABLE I

Osc. No.	Gen.	Fig. No.	Gen. V. Effect.	Ph.	Maximum Current Values 1st Alt.	2nd Alt.	I_1+I_2	Meth. (b). I_{max}	I_o.	Meth. (a) I_{max}.
1	1	3	6600	A	4 100	10 900	15 000	14 500	[illegible]	14 000
				B	0	14 100	14 100	14 100	[illegible]	13 300
				C	11 200	4 350	15 550	[illegible]	[illegible]	14 200
2	1	...	7700	A	12 800	5 600	18 400	17 500	19 000	17 000
				B	2 970	13 100	16 070	[illegible]	[illegible]	15 200
				C	0	15 600	15 600	15 600	17 400	15 600
3	1	...	8800	A	14 500	7 100	21 600	[illegible]	22 000	19 700
				C	0	17 500	[illegible]	17 500	[illegible]	17 500
4	2	4	8000	A	39 000	7 900	46 900	46 000	49 800	[illegible]
5	2	...	6000	A	18 400	10 2 0	[illegible]	27 000	[illegible]	28 400
6	2	..	6000	A	23 800	4 700	28 500	[illegible]	35 500	32 000
7	2	...	4000	A	14 600	14 100	28 700	26 000	30 400	27 300
8	2	...	2600	A	4 200	16 500	20 700	20 200	22 300	[illegible]
9	3	5	8000	A	9 150	2 800	11 950	[illegible]	[illegible]	11 500
				B	2 650	8 300	10 950	10 600	[illegible]	10 400
				C	0	12 000	12 000	12 000	13 000	11 700
10	3	...	8000	A	10 500	1 330	11 800	11 700	13 200	[illegible]
				B	4 200	6 900	11 100	10 400	12 400	11 200
				C	0	10 900	10 900	10 900	12 700	11 400

*The reactance is strictly defined by the equation of the short-circuit wave involving both sine and logarithmic curves. The sine component alone has been used merely to simplify matters without in any way affecting the result.

and short-circuit current hold with the combination of generator and external reactance coils sometimes used, keeping in mind the variable difference between I_o and I_{max}. With reactance coils connected in the generator leads or between generator bus-bar sections, so that the generator terminal voltage is greatly reduced under short-circuit conditions, the internal generator reactance (as above defined) and external reactance (as calculated or measured under steady current conditions) may be combined as with different reactances in any similar circuit; for example, to consider the simplest case, with a single generator and single reactance in each generator lead the short-circuit current will be:—

$$I_{max} = \frac{1.8\ E}{(\text{internal} + \text{external})\ \text{reactance}}$$

With reactance coils connected in the feeder circuits of such high reactance that in case of a short-circuit on the feeder, the generator terminal voltage is practically constant the maximum current in the feeder under short-circuit conditions can be determined accurately from the exact equation representing the current in a circuit containing reactance and resistance and to which a constant alternating voltage is suddenly applied. The current can be obtained more approximately from the same relations given in the case of the generator alone, considering only the external reactance. Obviously, with constant voltage the ratio between I_o and I_{max}. will be greater than 0.9.

Pending agreement, of at least national scope, it will be necessary to define the terms "short-circuit current" and "reactance" whenever they are used in connection with generator short-circuit phenomena. The following definitions are suggested:—

The short-circuit current of a generator shall be the peak value of the first cycle of current in one phase after a short-circuit is established, when the short-circuit occurs at that point in the voltage wave of the phase in which the current is measured resulting in maximum. short-circuit current. Short-circuit of the complete winding shall be assumed unless other conditions are specified.

The transient reactance of a synchronous generator shall be defined by the relation:—

Reactance $= \frac{E}{I}$, in which E is the maximum value of the voltage at the instant before short-circuit, and I the corresponding maximum value of the *sine component* of the short-circuit current.

It follows from these definitions that the *ratio of the short-circuit current to the peak value of rated current* is approximately equal to 180 divided by the reactance in percent.

The Effect of Limiting Reactances on the Application of Oil Circuit Breakers

J. N. Mahoney

A NUMBER of the large power systems, operating at 6 600, 11 000 and 13 200 volts, three phase, have adopted feeder reactances as a part of the permanent plant equipment. In several of these cases bus-tie reactances also are used, and in some instances the bus-tie reactances are short-circuited by knife switches or appropriate oil circuit breakers when one bus section is to be fed from the other sections. In practically all of the installations the minimum reactance values used range from what is known as two percent to a maximum of four percent, with a conducting capacity of from 200 to 300 amperes per phase. The two percent reactance is usually that having the lower current values. The reactance percent value referred to equals the percent of voltage drop, in terms of normal voltage, when the normal rated current is flowing. The values of ampere capacity and reactance chosen would indicate that it was the intention of the engineers applying them to limit the flow of current under short-circuit conditions to a value somewhere between 5 000 and 10 000 amperes. Where short-circuit currents or k.v.a. are mentioned, minimum possible values are meant.

By comparing the values of current and normal operating voltages above mentioned, it will be noted that these represent short-circuit kilovolt-ampere values of from 57 000 k.v.a. at 6 600 volts and 5 000 amperes, three-phase as a minimum, to 228 000 k.v.a. at 13 200 volts, 10 000 amperes, three-phase as a maximum. In a large plant where the necessity for limiting reactances usually exists, and with a large proportion of the capacity of the plant in operation, these values are likely to be sustained for any reasonable period at the will of the operators.

Oil circuit breakers are rated under the assumption of a decreasing short-circuit characteristic on apparatus having a definite maximum characteristic* This rating, reduced to its simplest terms, indicates that the circuit breaker is guaranteed to clear a short-circuit at normal voltage with a current flow equal to 6.25 times the rating in kilovolt-ampere breaking capacity of any particular type of oil circuit breaker. This data indicates that 6.25 times the rating should

*See "Breaking Capacity Rating of Oil Circuit Breakers" by the author in the Journal for November, 1913, p. 1 103.

equal approximately the actual kilovolt-amperes obtainable through the limiting reactances, with full normal voltages on the bus-bar behind the reactances. To illustrate:—A 200 ampere, four percent feeder reactance, three-phase, at 13 200 volts will pass 5 000 amperes per phase, or approximately 115 500 k.v.a. The circuit breaker that should be applied for this, without further consideration of the particular oper-

FIG. 1—PRESSURE CURVES SHOWING TANK PRESSURES IN TWO SIZES OF CIRCUIT BREAKERS IN CLEARING A SHORT CIRCUIT

ating conditions, should have a kilovolt-ampere breaking capacity rating equal to 115 000 ÷ 6.25, or approximately 18 500 k.v.a.

On account of the difference in conditions brought about by the electrical location of the reactance and generating apparatus in relation to the circuit breaker, this calculated application is not always a correct assumption. This is discussed on page 194 of this issue. When the reactance in the generator circuits and bus circuits is such as to reduce the values above mentioned, the circuit breaker rating can be reduced proportionately. When the feeder reactance controls but a single feeder and the plant is capable of sustaining approximately full voltage on the bus, because of the large capacity available and absence of generator or bus reactances, new conditions, ordinarily overlooked, are presented.

These effects are best illustrated by reference to Figs. 9 and 10 on pages 192 and 194 of this issue. These figures show the voltage conditions in clearing a short-circuit through various limiting reactances. It will be noted that the arc voltage persists for several cycles and has a relatively high average value. This indicates that considerable energy is dissipated in the circuit breaker tanks, and appears as mechanical pressure which the circuit breaker is compelled to withstand.

An indication of the pressures resulting in two sizes of circuit breaker clearing a similar short-circuit through limiting reactances, is given in Fig. 1. The tests, of which these pressure curves are a partial record, were conducted on one of the largest operating systems in the country. The pressure records were made while the circuit breakers were clearing a short-circuit of approximately 6 500 amperes per phase, three-phase, at 4 700 volts. The limiting reactances used were three percent at 4 500 volts and 300 amperes. The upper curve of the record, made on the smaller circuit breaker, indicates a maximum pressure, taken just above the oil level, of approximately 82.8 pounds, and the lower curve on the large circuit breaker, of approximately 31.8 pounds maximum.

As a comparison with these Fig. 2 (and Fig. 5, p. 198, and Fig. 11, p. 195) show much greater current values being interrupted by the respective circuit breakers without the persistency or pressures noted above. Fig. 2 shows a circuit breaker clearing a short-circuit directly on a bus on which was operating 30 000 k.v.a. of 12 000 volt generating apparatus The current values reached a maximum of approximately 16 000 amperes. The plant was operating under a load at the time, and it will be noted that the dynamic short-circuit current flow was cut off by the circuit breaker with very little voltage disturbance. This is also shown on Fig. 11, p. 195, which is an oscillogram showing the voltage readings across the terminals of a circuit breaker clearing a short-circuit in a circuit having the current values and other characteristics as shown in Fig. 5, p. 198. It will be noted that the arc persisted but one-half cycle with no unusual voltage disturbance on clearing the short-circuit, even though the apparent energy interrupted was greater than in Figs. 6 to 10 on pages 191 to 194.

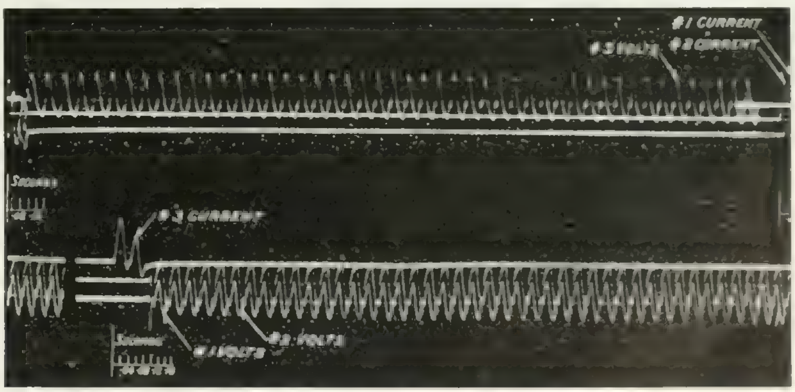

FIG. 2—OSCILLOGRAPH SHOWING A CIRCUIT BREAKER CLEARING A SHORT-CIRCUIT ON A BUS CARRYING 30 000 K.V.A. OF GENERATING APPARATUS AT 12 000 VOLTS

Current Limiting Reactance Coils

J. F. Peters

CURRENT LIMITING reactance coils, whether placed in generator leads for sectionalizing busses or in feeder circuits, will in many cases be required to carry comparatively large currents. This current can be provided for either by employing one large conductor or several comparatively small conductors connected in parallel. The voltage of these coils should vary directly with the current from zero to the maximum current under short-circuit; therefore they must be constructed without an iron core and cannot be mounted in an iron case. This requires that they be air cooled. Due to this fact, a comparatively large amount of conductor surface must be provided to dissipate the I^2R loss, and since the area of a conductor such as a cable increases with the square of its diameter while the surface increases with the first power of the diameter, it is obvious that the smaller the diameter of the cable the more efficiently is the copper worked. The copper represents a large part of the total cost; therefore it should be reduced to a minimum.

When a number of cables are connected in multiple in a coil of this kind, there is a tendency for local current to circulate between the parallel conductors due to the dense magnetic field cutting the coil. This circulating current may be of a large value and cause an excessive loss and prohibitive temperatures unless the conductors are so wound that all parallel circuits will have substantially the same impedance and thereby eliminate these currents.

The mechanical stresses in coils of this kind, which are due to the large number of ampere turns, should not be overlooked as they may be considerable. When the coils are built in a cylindrical form, three factors of mechanical stress should be considered; (a) the stress tending to increase the diameter of the coil, (b) the stress tending to shorten the coil, (c) the stress tending to pull the conductors together. The stress under (a) is radially outwards and is one of tension on the cable of which the coil is wound. This stress is independent of the diameter of the cable since the tensile strength is constant per minute area of conductor and the current producing the stress is constant per unit area of conductor. The stress (b) is one of compression on the supports between conductors. No difficulty should be experienced in providing for this unless the coil is abnormally long as compared with its diameter. The stress (c) tends to deflect the conductors between supports toward the middle of the coil in a direction parallel with the axis of the coil and varies with the fourth power of the diameter of the cable, viz., varies with the square of the current, which in turn varies with the square of the diameter of the cable; but the resistance of the cable to the bending moment also varies approximately with the fourth power of the diameter of the cable, so that the tendency of the cables being drawn together is independent of the diameter of the cable of which the coil is wound. This tendency for a deflection of the cable is partially offset by the stresses mentioned in (a) which tend to maintain a true cylindrical shape.

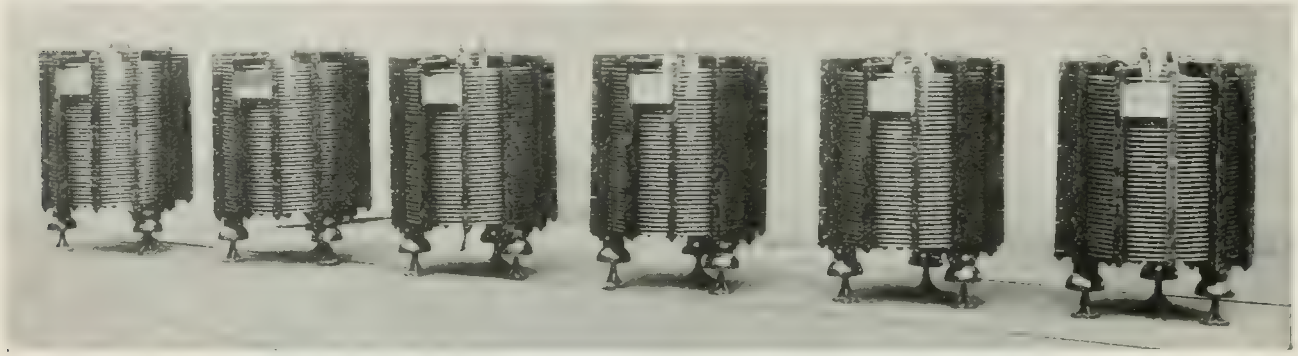

FIG. 1—GROUP OF COMPLETELY ASSEMBLED REACTANCE COILS

These coils are rated as five percent of an 11 000 volt, 200 ampere, three-phase circuit. They have been tested to 20 000 volts at 100 000 cycles across the terminals, induced by making the coil the secondary of a closely coupled Tesla transformer, the voltage being measured by a sphere spark-gap. This is equivalent to 1 100 volts between conductors in adjacent layers—3.2 times the value produced when the entire generator rated voltage is impressed upon the coil.

It will be seen from the foregoing that from the standpoint of economy in material there is an advantage in using a number of comparatively small cables in parallel in the construction of these coils, provided circulating currents can be prevented.

In Fig. 2 is shown one of three current limiting reactance coils for use with a 21 100 k.v.a., three-phase generator which has a normal full-load current per lead of 1 100 amperes. The coil is made up of seven stranded bare copper cables connected in parallel. The cables are so wound that they all have substantially the same length and impedance, which entirely eliminates circulating currents. The cables are wound into grooves in specially prepared, moulded fireproof supports, or cleats, as shown by Figs. 2 and 3. A number of these cleats can be seen hanging on the tie rods. The seven cables enter the coil at seven

equidistant points around the inner periphery of the bottom layer. The first cable occupies the inner circumferential row of slots for one-seventh of a turn, then it passes out to the second row of slots and the second cable occupies the inner row. These two continue in this position for the second seventh turn at the end of which they step outwards one more row while the third cable enters on the inner row of slots. This procedure of stepping outwards at the end of every one-seventh of a turn is continued until all the cables have been entered. When the outermost cable has filled the last outer slot, the second level of cleats is dropped down and this outermost cable is carried to the outer row of slots in the new layer of cleats. It is wound in this position for the next one-seventh turn where it steps inward one row of slots making room for the second cable to occupy the outer slots. This is continued until all cables have passed on to the second layer of cleats. It will be noted that since there are six slots in each cleat and seven cables being wound, the first cable will have entered the second layer before the last cable has started on the first layer. However, it will be seen that since there is a shift from one circumferential row of slots to the next at every one-seventh of a turn, each cable passes through exactly the same distance in each row of slots in each layer. Therefore the number of slots in the cleats does not need to be a multiple of the number of cables being wound. The winding of the cable is continued back and forth in discoidal or pancake layers until the coil is complete, at which point the cable will terminate on the inside of the last layer, since there is an even number of layers, and at seven equidistant points around the inner periphery of the coil.

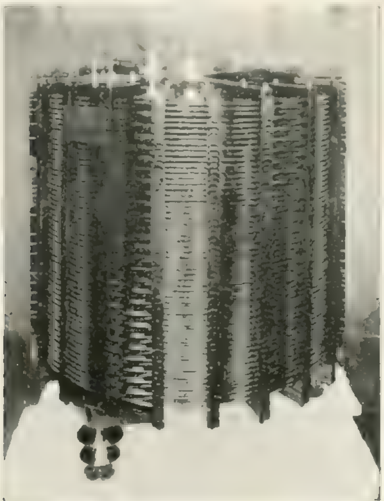

FIG. 2—SINGLE REACTANCE COIL

One of three for use with a 21 100 k.v.a., three-phase generator of 1 100 amperes normal full-load current.

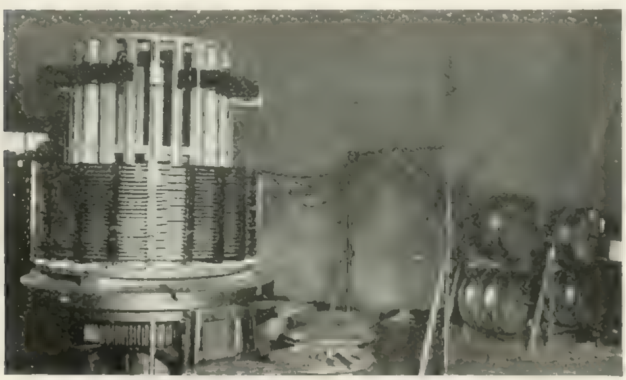

FIG. 3—VIEW SHOWING METHOD OF WINDING REACTANCE COILS

The maximum voltage between adjacent conductors is that due to two layers, and since each layer consists of six-sevenths of an electrical turn, the voltage is equal to that due to one and five-sevenths electrical turns. The spacing between turns and between layers is ample for this stress.

The moulded cleats with slots into which the cable is wound have holes in each of their ends through which brass rods covered by insulating tubes are placed for clamping the layers securely together.

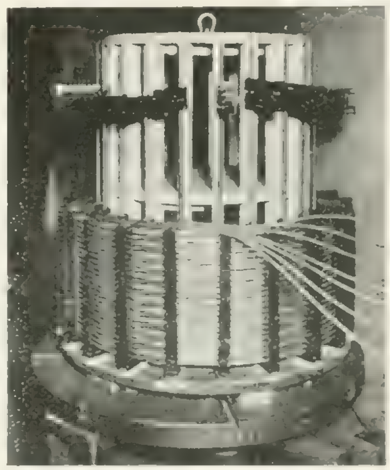

FIG. 4—DETAIL VIEW OF COIL IN FIG. 3

On the top and bottom of each tier of cleats is placed a non-magnetic metal cleat, shown in Fig. 2, which allows the coil to be clamped tightly together. The moulded cleats between layers are under compression due to the weight of the coil as well as the magnetic pull tending to shorten the coil. But the spacing between columns of cleats is sufficiently close so that this stress is provided for with a large factor of safety. This spacing is also sufficiently small so that there will not be any appreciable deflection of the cable between cleats under the most severe rush of current to which the coil can be subjected under operating conditions. The stress tending to deflect the cable parallel with the axis of the coil may sum up to a considerable value at a point one-half way up the coil, but this stress is an accummulation of the stresses of the turns in one-half of the coil. Since the turns are self-supporting between cleats, the stress on any individual cable is small, the stress being transmitted through the cleats to the center of the coil. The magnetic stress tending to increase the diameter of the coil is much greater than the one tending to shorten

the coil. This stress is one of tension on the cable. The tensile strength of copper is sufficient to resist this stress without question.

Since the magnetic stresses tend toward maintaining a true cylindrical form for the coil, it is not necessary to brace the individual coils, either on the inside or outside. It will be noted from the illustrations that these coils are free from all massive supports, thus giving a free unobstructed circulation of air. A three-way form of support, shown in Fig. 3 at each end of the coil serves as a brace or spreader while handling the coil, and also serves as a support for the terminals. Two brass rods pass through the opening of the coil and are supported by porcelain bushings held in place by the three-way support, and on each end of each rod is provided a line terminal. All the cables at one end of the coil are connected to one rod by means of interleaf connectors, while the other ends of the cables are connected to the second rod. This enables the coils to be installed with both leads at either the top or the bottom of the coil, or one lead at the top and the other at the bottom. The coil is supported on three non-magnetic castings, each of which spans four tiers of cleats. Into these castings is cemented three liberally designed insulators which rest on metal pins suitable for cementing or bolting to the floor. Twelve of the tie rods passing through the cleats are made long enough to engage with three metal plates into which eye bolts are placed for convenience in handling the coil.

These coils under normal operation give a rise in temperature of less than 50 degrees C. above the surrounding air. There is no inflammable material used in their construction, so that temperatures two or three times the above value can do no harm; therefore these coils can carry more than 200 percent load continuously without dangerous temperatures.

The Mechanical Stresses in Reactance Coils

W. M. Dann

A STUDY of the stresses that tend to cause physical injury to connected apparatus is interesting at the present moment when much attention is being given to the prevention of trouble at times of short-circuit. The value of air-core current-limiting reactances in protecting a system lies in the counter e.m.f. produced by a large leakage field. However, unless space considerations will allow the placing of the coils outside the range of influence of one coil upon another, it is this very field that creates the stresses which are the subject of this article. Their effects will be considered under normal conditions as well as under the abnormal conditions of short-circuit. It is the aim to give some conception of the dimensions of these stresses as they are not ordinarily expressed in terms of actual measurements.

These mechanical stresses are of two kinds; first, the internal stresses that affect the parts of the coils themselves, and second, the external stresses that affect adjacent coils mutually.

The portion of the leakage flux from one coil which threads through the conductors of a second coil and the current that flows in these conductors are the effective agents that produce the mechanical stresses. Since the field varies directly with the current, forces of attraction and repulsion are at any instant proportional to the product of the instantaneous currents in the two coils. The force as it is expressed in pounds is a measure of the average value of these instantaneous products. The tendency of the fields of adjacent coils when they combine is to adjust conditions to produce less reluctance in the magnetic circuit if possible. If two coils are mounted side by side in the same plane and the current flow is opposite in direction through them at a given instant, the fields will at that instant be opposite in direction. The path of the combined field will be in a closed circuit up through one coil and down through the other. The reluctance of this circuit would be lessened if the length of the path were shortened. Therefore, the tendency is for the two coils to pull together.

If the currents had been flowing in the same direction at the given instant, the flux would have had the same instantaneous direction through the coils and the return path would have been between the coils. The reluctance of this part of the circuit would be less if the coils were further apart, giving the magnetic circuit more area. Hence the tendency would have been for the coils to separate. If two coils are mounted one above the other with axes coincident, the same tendency of the flux to lessen the reluctance of the magnetic circuit will produce results just the opposite of the previous case. In other words, currents flowing in opposite directions through the coils at a given instant will produce a force of repulsion at that instant, while currents flowing in the same direction will produce a force of attraction. These instantaneous conditions of attraction and repulsion are illustrated in Fig. 1. It is obvious that the mutual forces between reactance coils in any circuit may be made either attraction or repulsion by adjusting the polarity of adjacent coils. Fig. 2 shows the variation of the instantaneous mutual forces between adjacent coils connected in a three-phase circuit with the instantaneous currents displaced 120 degrees. Steady balanced conditions and sine waves are assumed for these curves and the curves in Figs. 3 and 4. The shaded waves representing the mutual forces are obtained by multiplying the instantaneous current values. The waves above the

axis indicate repulsion, since they are formed when the currents are flowing in the same direction, and waves below the axis indicate attraction. The figures in the force waves are proportional to average force. For purposes of comparison they have been expressed in terms which will make the net average result unity for steady balanced conditions in a three-phase circiut. It will be seen that the net result for this connection is a force of attraction between coils. This will be

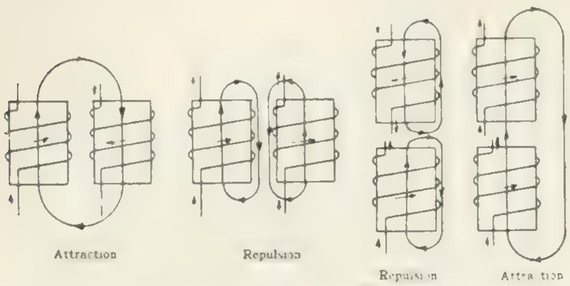

FIG. 1 DIAGRAM INDICATING ATTRACTIVE AND REPULSIVE ACTIONS BETWEEN ADJACENT REACTANCE COILS

the condition for coils mounted in the same plane with axes parallel, whether they are in a straight row or in an equilateral triangle formation.

With the middle coil reversed as in Fig. 3, the relative instantaneous currents are reversed, which reverses the net mutual force between adjacent coils.

The mutual stresses between coils *A* and *B* with the polarity of Fig. 2 when they are connected in series across a phase of the generator are shown in Fig. 4. This presents a comparison of the relative forces between three-phase and single-phase short-circuit conditions with a constant generator voltage, as the total impedance in the circuit is assumed to be the same as for Fig. 2. The single-phase current

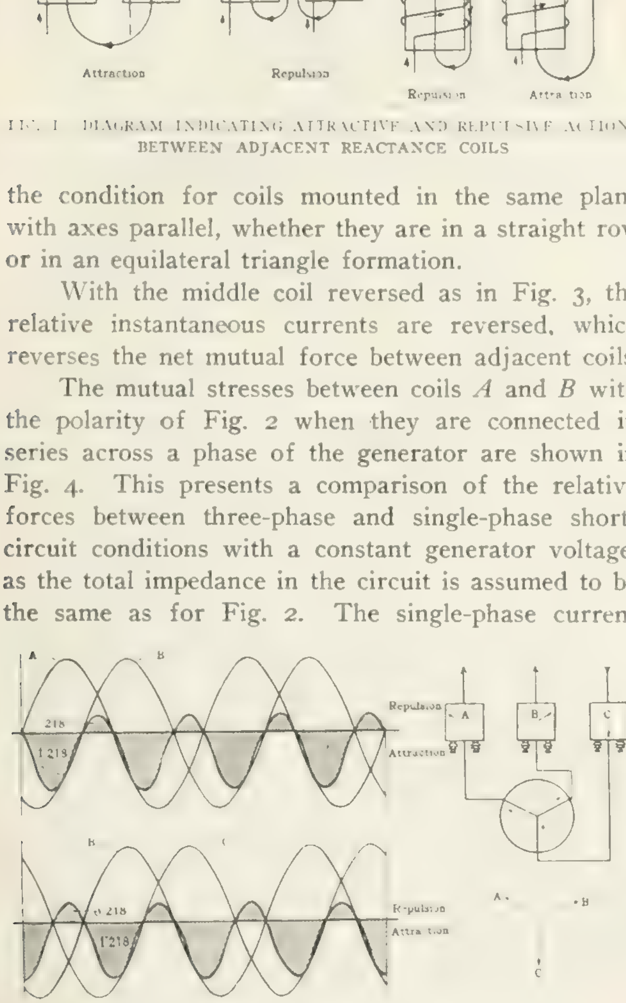

FIG. 2 CURVES OF INSTANTANEOUS MUTUAL FORCES

Coils mounted side by side in a balanced three-phase feeder under steady normal conditions. Currents in coils 120 degrees apart. Net force = one unit of attraction.

flowing is obtained with 173 percent voltage impressed across two reactances, producing 86.6 percent of the current per phase of Figs. 2 and 3. There are no negative loops of mutual stress in this case because the currents are always in phase. The shaded wave will be found to show 50 percent greater force of attraction than in the case of the three-phase conditions. If the relative polarities of *A* and *B* had been reversed, as in Fig. 3, this force would be repulsion.

If an air-core reactance coil is located near an iron column or is mounted directly above or below a floor composed of magnetic material, the flux passing through the iron causes an attraction between it and the coil. Similarly, if a coil is mounted directly above or below a closed metallic loop in which the field of the coil would cause a circulating current to flow, the mutual effects between the field of this circulating

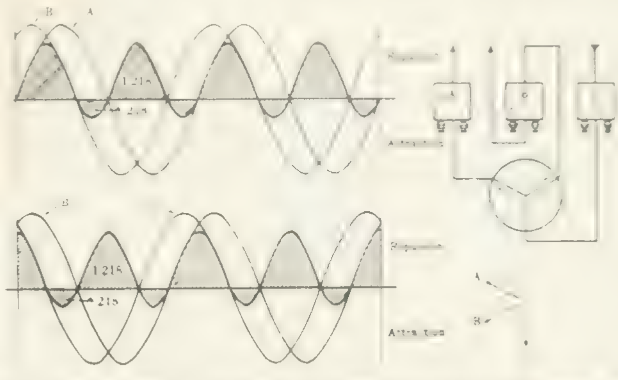

FIG. 3 CONDITIONS AS IN FIG. 2 EXCEPT THAT THE POLARITY OF THE MIDDLE COIL IS REVERSED

Net force = one unit of repulsion.

current and the field of the coil would result in repulsion. Experiments have shown that for the same spacing these forces are of much smaller magnitude than the mutual stresses between coils. From the standpoint of stresses they are unimportant if the spacing between coils and iron is the same or even somewhat less than that between coils.

The foregoing paragraphs deal with mutual stresses under steady conditions. At the time of a short-circuit, the transient effects disturb the relations existing under steady conditions. They can create instantaneous stresses of much greater in-

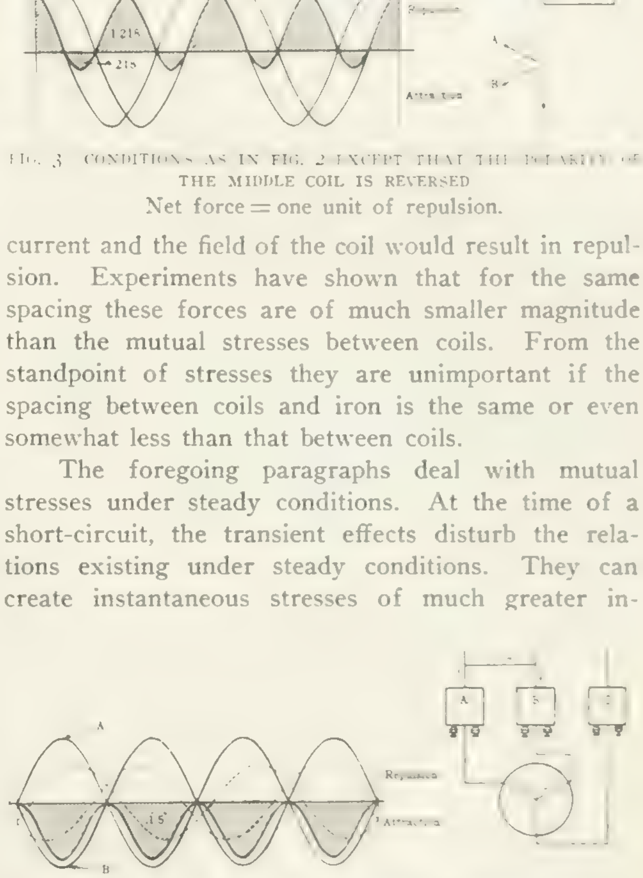

FIG. 4 CURVES OF INSTANTANEOUS MUTUAL FORCES

Between reactance coils *A* and *B* of Fig. 2 with the generator voltage across two coils in series. Force = 1.5 units of attraction. For the reversed polarity of Fig. 3, force would be 1.5 units of repulsion.

tensity than would be produced by the final steady value of the short-circuit current. Depending upon the point at which the short-circuit occurs, the maximum point of the current waves may be almost double the steady current under the abnormal conditions.

Fig. 5 shows curves made up to illustrate the conditions in the first two cycles after a symmetrical three-phase short-circuit occurring when the current in one line is zero. They are made up of sine waves and an assumed logarithmic decrement, and on the assumption of no drop of voltage. A similar set of curves, Fig. 6, shows the worst conditions of stress

with a single-phase short-circuit constructed with the same assumption as for Fig. 5. While these curves are hypothetical, they give an idea of the difference in the stress conditions under normal conditions and during the transient period. They represent stresses so much greater than for the steady conditions that it is impracticable to present them to the same scale.

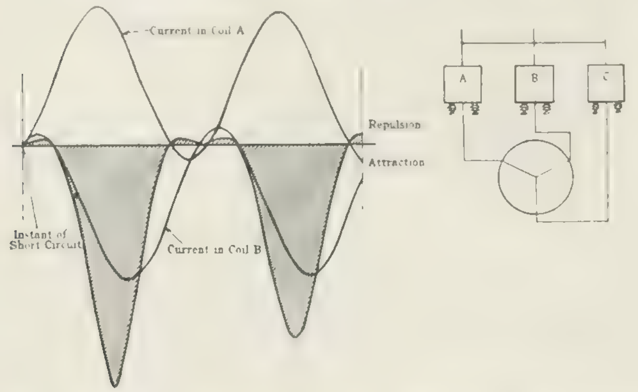

FIG. 5—DIAGRAM INDICATING FORCE CONDITIONS DURING THE TRANSIENT PERIOD OF SINGLE-PHASE SHORT-CIRCUIT

The maximum limit of mutual stress in the first cycle of the transient period, with a symmetrical three-phase short-circuit, if the time-constant of the circuit is neglected, is four times the stress which would occur if there were no transient effects. If the generating equipment were of infinite capacity so that its impedance could momentarily be neglected in computing current, the maximum average stress that could be produced in the first cycle after a three-phase short-circuit, with five percent reactances in the feeder, would be $4\text{x}\left(\frac{100}{5\%}\right)^2$ or 1 600 times the average stress of the normal operating conditions. Practical considerations, such as the impedance of the generating equipment, and the time-constant of the circuit, which affects the rate of coming back from the transient conditions to the steady conditions, will reduce this factor. Loss of voltage due to armature

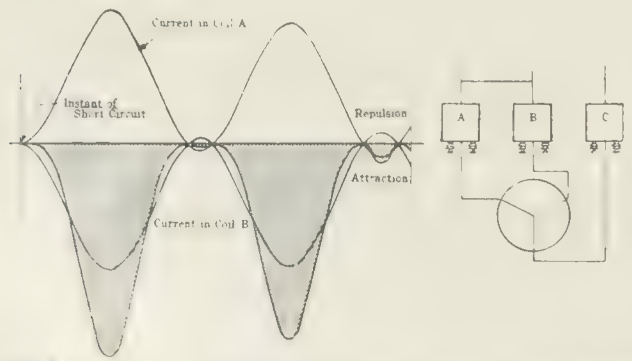

FIG. 6—DIAGRAM OF FORCES DURING THE TRANSIENT PERIOD OF A BALANCED THREE-PHASE SHORT-CIRCUIT

reactions can be neglected as not being of much importance in the first few cycles after a short-circuit and, for rough comparative purposes, form-factor of the wave can also be neglected.

Assuming a generating station with a normal capacity of 60 000 k.v.a. made up of three 20 000 k.v.a., 11 000 volt, three-phase turbo-generators of typical design, with 14 percent "transient reactance," and still neglecting time-constant, the ratio of the maximum possible average stress of the transient conditions to the normal average stress would be reduced to approximately 1 300. Assuming that the time-constant of the circuit reduces the current strength ten

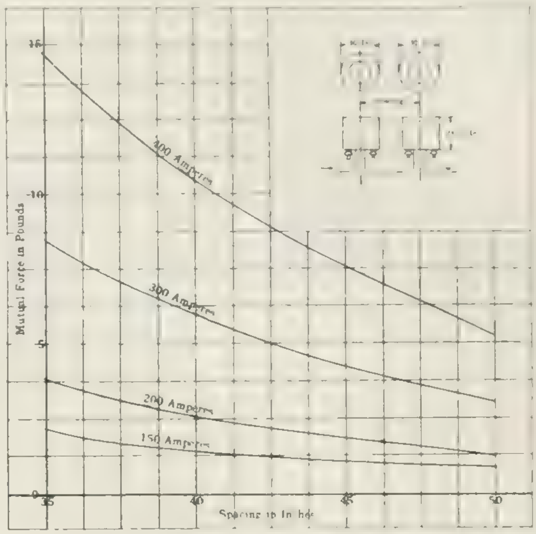

FIG. 7—CURVES OF MUTUAL FORCES

Forces in lbs. between two adjacent five percent reactances for a 60 cycle, 200 ampere, 11 000 volt, feeder with different spacings between axes.

percent in the first cycle after the short-circuit, this ratio would be further reduced to roughly 1 000. This is the ratio used for the data in Tables I and II referring to the probable maximum stresses for a three-phase short-circuit in a 60 000 k. v. a. system.

The average mutual stress in the first cycle of the transient period with a single-phase dead short-circuit cannot exceed four times the stress which would occur if there were no transient effects. With five percent reactances in a feeder connected to a system of infinite capacity, and, neglecting time-constant, the average stresses at such a time could not be more than 1 600 times the average stress of the normal conditions. Considerations of generator impedance and time-constant as before will bring this ratio down to roughly 1 000 for the 60 000 k.v.a. station assumed. This is the ratio used for the data in Tables I and II referring to the probable maximum stresses for a single-phase short-circuit in a 60 000 k.v.a. system. It must be realized that these maximum limits of stress are momentary and that they decrease

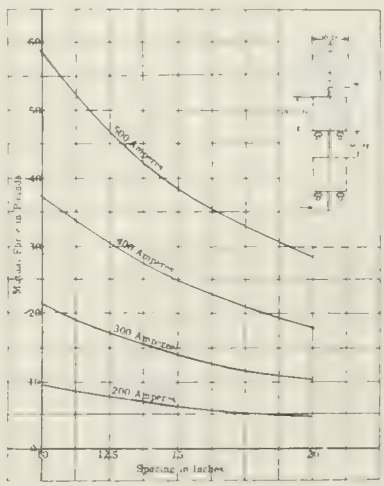

FIG. 8—CURVES OF MUTUAL FORCES

Forces in lbs. between the reactance of Fig. 7 mounted one above the other with axes coincident.

very rapidly after the first cycle, as shown in Figs. 5 and 6.

The internal mechanical stresses in reactance coils depend upon the amount of current flowing and are independent of spacing between coils. While the mutual stresses for given conditions are more severe with a single-phase short-circuit than with a three-phase short-circuit, the internal stresses are more severe when the three-phase short-circuit occurs.

The curves shown in Figs. 7 and 8 give in concrete form some idea of the mutual forces in pounds that exist between two reactance coils under differing conditions of current and spacing. This data is based on careful tests made with reactance coils of the type shown in Fig. 3, on page 189 of this issue. In order to eliminate friction during the tests, a coil was raised slightly above the level of the floor and was suspended in this position from a point in a high ceiling. Its position with regard to a second coil was then fixed by properly locating the second coil. The position of the suspended coil with no current flowing was indicated with a plumb-bob and mark. Careful measurements of pull were then made when the plumb-bob indicated the position of no current. Single-phase current with a wave form approximating a sine wave was passed through both coils in series to eliminate any question of relative currents in the two coils at any instant. The coils used were five percent coils for a 200 ampere, 11 000 volt, 60 cycle feeder on a three-phase system. A summary of the tests, reduced to terms of normal and short-circuit conditions, appears in Tables I and II.

TABLE I NORMAL AND SHORT-CIRCUIT MUTUAL FORCES BETWEEN TWO ADJACENT FIVE PERCENT REACTANCES MOUNTED SIDE BY SIDE ON A 200 AMPERE, 11 000 VOLT, 60 CYCLE FEEDER

	Three Phase			Single Phase		
Spacing in inches from center to center	Steady conditions	Transient conditions		Steady conditions	Transient conditions	
	Normal 100 per cent voltage 200 amperes lbs. force	Maximum probable force in lbs. with 60 000 k. v. a. generator capacity	Maximum possible force in lbs. with infinate generator capacity	Normal 100 per cent voltage 173 amperes lbs. force	Maximum probable force in lbs. with 60 000 k. v. a. generator capacity	Maximum possible force in lbs. with infinate generator capacity
35	2	2000	2600	3	3000	4000
40	1.33	1300	1700	2	2000	2600
45	1.0	1000	1300	1.4	1400	1800
50	0.67	670	870	1.0	1000	1450

This data is reasonably accurate for the normal conditions. It is necessarily very approximate for the short-circuit conditions. It is intended to indicate the order of the worst stresses to be expected, with transient conditions favorable for large stresses. Conditions with regard to the point of the waves at which short-circuits occur can reduce them very materially and their severity will be lessened with a smaller generating station than that assumed.

The following conclusions may be drawn from the foregoing:—

1—Reactance coils can be connected in a three-phase circuit to produce forces either of attraction or repulsion. The mutual inductance between adjacent coils adds to this self-inductance of the coils with the connection for attraction, but the gain in protection for the circuit is very slight. The choice of polarity would depend upon what is the most desirable method of bracing in the particular installation.

2—The internal stresses cannot be modified by methods of installing. They are one-third greater with a three-phase short-circuit than with a single-phase short-circuit.

3—The force per ampere of single-phase current is double the force per ampere of three-phase currents displaced 120 degrees. Since the current for a single-phase short-circuit is 86.6 percent of the current for a three-phase short-circuit, the mutual stresses become only 1.5 times the stress in a three-phase short-circuit.

4—The forces between coils due to normal conditions and even the momentary forces due to ordinary short-circuits are inconsiderable and would require nothing more than fastening the feet on the floor.

TABLE II—NORMAL AND SHORT-CIRCUIT MUTUAL FORCES BETWEEN TWO ADJACENT FIVE PERCENT REACTANCES, MOUNTED ON ABOVE THE OTHER, ON A 200 AMPERE, 11 000 VOLTS 60 CYCLE FEEDER.

	Three Phase			Single Phase		
Spacing in inches from conductor to conductor	Steady conditions	Transient conditions		Steady conditions	Transient conditions	
	Normal 100 per cent voltage 200 amperes lbs. force	Maximum probable force in lbs. with 60 000 k. v. a. generator capacity	Maximum possible force in lbs. with infinate generator capacity	Normal 100 per cent voltage 173 amperes lbs. force	Maximum probable force in lbs. with 60 000 k. v. a. generator capacity	Maximum possible force in lbs. with infinate generator capacity
10	4.5	4500	5800	6.8	6800	8800
12.5	3.5	3500	4600	5.2	5200	6800
15	3	3000	3900	4.5	4500	5800
20	2.7	2700	3500	4.0	4000	5200

5—The worst forces due to short-circuits occurring under the most favorable conditions for large stresses should be provided against with bracing between coils.

6—The maximum possible momentary forces for the particular coils used in these tests indicate that they can be placed side by side with a spacing as small as 40 inches from center to center (one-third the diameter apart) without encountering stresses that cannot easily be taken care of.

7—The maximum possible forces with the coils placed one above another indicate that a greater spacing between coils is necessary on account of the mutual effects of the more intense field at the ends.

8—The matter of spacing depends upon the physical dimensions of the coils and the ampere-turns involved. The data in Tables I and II can be regarded as typical of this type of coil for approximately the same duty, but not for an unlimited range of size and capacity.

The Ventilation of Rotating Electrical Apparatus

R. E. Gilman

THE VENTILATION of rotating electrical machines is a very broad subject, as it involves directly or indirectly all the features of the design. It is not possible in a short article on the subject to cover the problem completely, and thus in this article only the essential factors are outlined along with illustrations of some of the methods employed in specific cases.

IN any conversion of energy the efficiency of transformation is less than 100 percent. In an electrical machine this difference between input and output is converted into heat, which is objectionable, entirely aside from the loss of efficiency, on account of its possible injurious effects upon the insulating materials used in constructing the machine. When any machine has reached a constant temperature rise, the heat generated inside of it is being dissipated into the surrounding medium at the same rate at which it is produced. As this medium is air, the problem of ventilation presented is to determine the losses, both as to their amount and location, and then to provide the necessary surfaces properly located and the necessary volume of air in contact with those surfaces to dissipate the heat produced at any point without exceeding some specified temperature rise at that point.

There are four primary elements of any machine:—First, the copper conductors provided for carrying the currents; second, the magnetic path provided for the flux; third, the materials employed to insulate the current paths from the magnetic paths; and fourth, the framework of the unit which is necessary to hold the rotating and stationary parts of the machine in their proper relative positions and also to transfer mechanical forces.

In the copper circuits there are I^2R losses due to the exciting and the line currents; also there may be other I^2R losses induced by the action of either the main flux or the leakage flux across the slots, creating local currents in that part of the armature conductor which is imbedded in the iron. In machines with open slots and high flux densities in the air-gap, this local loss may equal or even exceed that due to the line current. Further, the flux produced by the magnetomotive force of the armature conductors in any slot creates leakage fields of a variable density throughout the depth of the slot, and these fields generate eddy current losses in the conductors. These losses may, in the case of conductors of large cross-section, exceed the normal I^2R losses of the line current. Such losses can, however, be prevented to a large extent by laminating properly the individual conductors in any slot and also by transposing the various conductors in a phase group so as to equalize the induced voltages due to the leakage flux.

It is evident that in machines of considerable width of core these extra copper losses have a relatively greater value than in the short units and also that, on account of the width of core, it is more difficult to dissipate them.

In that part of the magnetic circuit which is subjected to changing flux, there are hysteresis losses in the iron and eddy current losses in local circuits in the iron. It is customary to break up the path of the eddy currents by laminating the iron and insulating the laminations from each other. Eddy currents also exist in such parts of the machine as the end bells and stationary end plates or, in fact, in any metal part of the machine which is exposed to changing flux. Even in the pole faces, ordinarily considered as a part of the magnetic circuit in which the flux is stationary, eddy currents are induced by the pulsation of the flux in the air-gap caused by alternately bringing a tooth and then a slot opposite to a fixed point on the pole face. These losses in the pole faces may become considerable if the pole is of solid material, and more especially so if the opening of the slots in which the armature coils are located is relatively large compared to the air-gap. There are also losses due to friction on the air which are not important except in the case of large machines at high speed where a considerable volume of air is set in motion at a fairly high velocity.

The metal parts of a machine are fairly good conductors of heat and we find only a relatively small heat gradient in different parts of the same continuous mass for short distances, but the introduction of insulating materials, which are always poor heat conductors, complicates the problem of heat distribution. The insulation of an armature coil, especially a high voltage coil, permits a very considerable difference in temperature between the inside and outside of the insulating tube before any appreciable heat transfer is made. The insulation used between the laminations of the iron also retards the flow of heat from one plate to the next. In fact, for the same difference in temperature, heat can be transferred about ten times the distance within the plate that it can be transferred across plates.

It can readily be seen from the above outline of the losses and their distribution that there is a tendency for local hot spots to exist, more particularly in machines of great axial length and, as it is essential in order to utilize to the best advantage the materials of construction to equalize the temperature rise at various points of the same element, special provision has to be made to provide air at those points where heat is generated.

Three cases exist in any machine by means of which air can be brought into contact with the heated parts:—First, a current of air can be directed against a surface as in the case of the stationary windings; second, a rotating body of approximately cylindrical shape creates a circulation of air in intimate contact with its surfaces; third, air may be confined to definite channels and supplied at the necessary pressure to force its way through those channels, as in the case of ducts through the iron. The laws of cooling are different in the three cases and, in fact, no general law can be given for any particular case. However, all three ways of cooling exist in almost every machine, and the system of ventilation varies only in the extent to which each of the above methods is employed.

FIG. 1 TYPICAL OPEN CONSTRUCTION

Slow speed, direct-current generator, showing simplicity of ventilation for such machines.

The above roughly outlines the problems in ventilation that confront the designer, and it is obvious that if it were possible to make several radically different designs for a given rating that each would present a different problem in ventilation. It is possible, however, to indicate quite readily the class of machine which is most difficult to ventilate. If a given machine is considered and its speed doubled, the total losses would be approximately doubled, and for the same current per conductor it would be possible to get double the output. The mass of the material would be unchanged and, roughly speaking, there would be twice the loss per unit of material. On the other hand, keeping the same speed and doubling the length of the machine, it is again possible to get twice the output, and there would be approximately twice the losses. Both the above cases would be more difficult to ventilate than the initial machine, the first on account of the increased loss per pound of material, and the second on account of the difficulty in forcing the air to the center of the machine. A little consideration will show that for two machines of approximately the same efficiency and of the same output, and at the same frequency, but designed for different speeds, the unit of highest rotational speed will be the most difficult to cool. It can be said in general, therefore, that the problem of ventilation grows more difficult with increase in frequency, in output and in rotational speed.

FIG. 2 DETAIL OF FIELD COIL OF GENERATOR SHOWN IN FIG. 1, ILLUSTRATING OPEN CONSTRUCTION

The methods of cooling which have been applied to different classes of machines can, perhaps, be shown best by a few examples of modern machines. A good illustration of an open type generator is shown in Figs. 1, 2 and 3, which illustrate a direct-current generator arranged for connection to a relatively slow-speed engine. The construction of the stator and rotor and the details of the field coils, illustrate in an excellent manner what methods can be employed to allow free circulation of air through all parts of the unit. It is of interest to know that the output per pound of material of this class of machine is generally limited by the efficiency, rather than by the allowable temperature rise.

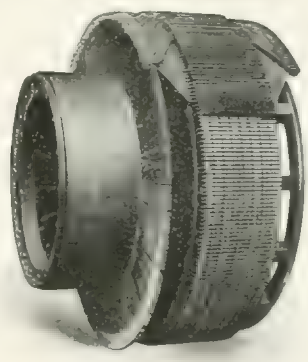

FIG. 3 DETAIL OF OPEN CONSTRUCTION SELF-VENTILATED ARMATURE OF GENERATOR OF FIG. 1

The same general features of construction can be employed in all direct-current generators and rotary converters of normal speed and output because this class of machine is always of relatively short core length and presents naturally ample radiating surface for carrying off the heat. In fact, in some rotary converters designed for low voltage and consequently, having a large number of poles and a relatively great diameter compared to the length of core, it is desirable to reduce the windage of the spider by enclosing the openings between the arms. In motor-generator sets, especially where the rotating elements of the two machines are close together, there is always a tendency for one unit to rob the other of air. This results generally in recirculating the air between the machines, and the consequent heating of those parts

of the machine adjacent to each other. Fig. 4 shows a scheme for introducing air between the machines. Both units are closed on the rear by end bells, and air taken from the base of the machine is supplied through a ventilator. Fig. 5 shows a modification of this ventilating arrangement in that an end bell is supplied only on the alternating-current motor, and

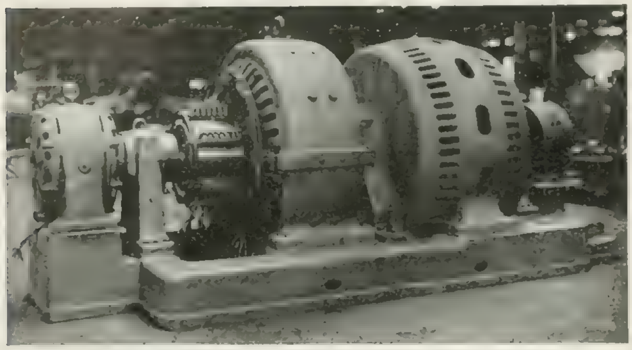

FIG. 4—METHOD USED TO INTRODUCE AIR INTO THE TWO MACHINES OF A MOTOR-GENERATOR SET

all air for cooling that side of the motor has to be passed through the spider.

On high speed direct-current commutators, especially where the current to be collected is large compared to the radiating surface of the commutator, ventilating vanes are frequently supplied at the outer end of the commutator. A scheme for doing this is illustrated in Fig. 6.

Alternating-current generators and motors can be conveniently divided under three classes:—Engine type or slow-speed, direct-connected type or intermediate-speed, and turbo-generators or high-speed units. For the slow-speed units, the usual construction does not differ materially as regards ventilation from the direct-current machine illustrated in Fig. 1. In the case of very slow-speed units it will be necessary occasionally to supply simple flat blade fans, in

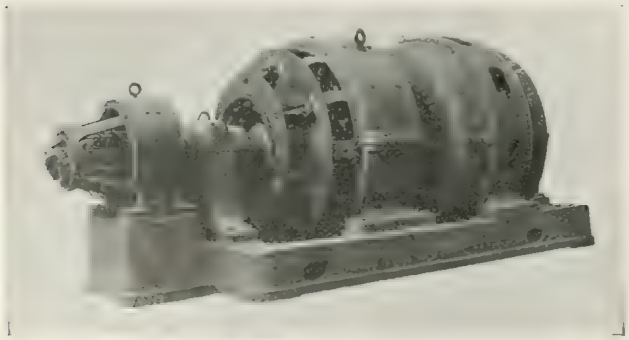

FIG. 5—A MODIFICATION OF THE SCHEME OF FIG. 4
End bell on alternating-current side only; ventilation through spider.

order to stir up the air about the stationary windings. For the intermediate speeds, the outputs increase and also the axial length is relatively greater compared with the pole pitch than in the case of the engine type machines. Pressure fans are, therefore, frequently necessary. These fans force the air into chambers formed by enclosing the stator with solid end bells, and in these chambers the air is circulated around the windings and afterwards escapes through openings in the iron, these openings ordinarily consisting of radial ducts.

For turbo-generators the modern trend in design is towards greater capacity per unit, and the use of the maximum possible speed for a given frequency. From the point of view of the electrical unit, these high speeds are not economically desirable, but the advantages of the unit as a whole have forced their adoption up to the limits of the safe working stresses in the material. The result is that, in general, the core of the turbo-generator is made as long as possible, and, consequently, it is impossible to force the air to the hot spots of the machine unless the unit is enclosed and the air delivered under pressure. In generators of small capacity, this air can be taken from the room and discharged back into the room, but for the larger units where a greater volume of air is required, it is usual to bring the air from some clean source through a duct and to discharge it from the machine through a similar duct. Totally enclosing the machine accomplishes two purposes:—First, it insures a fresh supply of air; second, it reduces the noise attendant on moving a large volume of air at a high velocity.

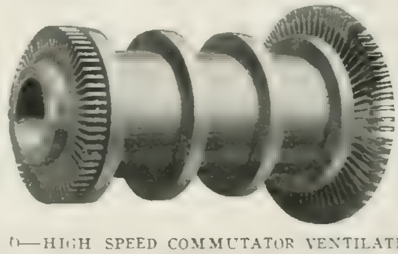

FIG. 6—HIGH SPEED COMMUTATOR VENTILATION
Showing vanes at outer end of commutator.

It is of interest, before considering any of the details of ventilation in turbo-generators, to estimate the volume of air required to carry off the heat from any machine. The weight of air in pounds per minute per kilowatt loss for an average temperature rise of T degrees C. of the air is given by the equation,

$$\frac{133 \times \text{kw}}{T} = \text{pounds of air per minute.}$$

The volume is given by the equation,

$$\text{Weight of air} \times \frac{270 + T}{22} = \text{Volume in cu. ft. per minute.}$$

For a rise in temperature of 25 degrees, about 70 cubic feet per minute per kilowatt loss would be required if the air were uniformly heated. As this is, however, not the case, it is customary to provide from 90 to 100 cubic feet of air per minute for each kilowatt loss. As an approximate figure, it is usual to estimate from 3.5 to 5 cubic feet of air per minute per kilovolt-ampere rating, the smaller figure applying to large machines. A 20 000 k.v.a. unit would require about 70 000 cubic feet of air per minute on this basis, and actual tests show that between 60 000 and 70 000 cubic feet of air per minute are required.

In cooling turbo-generators, there are two general methods of providing paths for the air,* the variation being principally in the arrangement of the ducts for cooling the stator iron. One method passes the air into the end bells, around the coils and thence through the air-gap, from which it passes through radial ducts in the iron and so out of the machine. This scheme is limited to the volume of air which can be passed through the air-gap. Before the cooling air reaches the iron it has to absorb the loss from the windings, the windage and friction losses and the rotor copper loss. It is evident that there will be some difference in the velocity of air through the different ducts in the stator, and also that the air in the center of the machine is likely to be at a different temperature from that on the end, so that a tendency towards local hot spots in the iron results. It is also evident that, as all the air which reaches the iron is heated before it comes in contact with the iron, the surface of the iron must be relatively great in order to allow a low temperature rise.

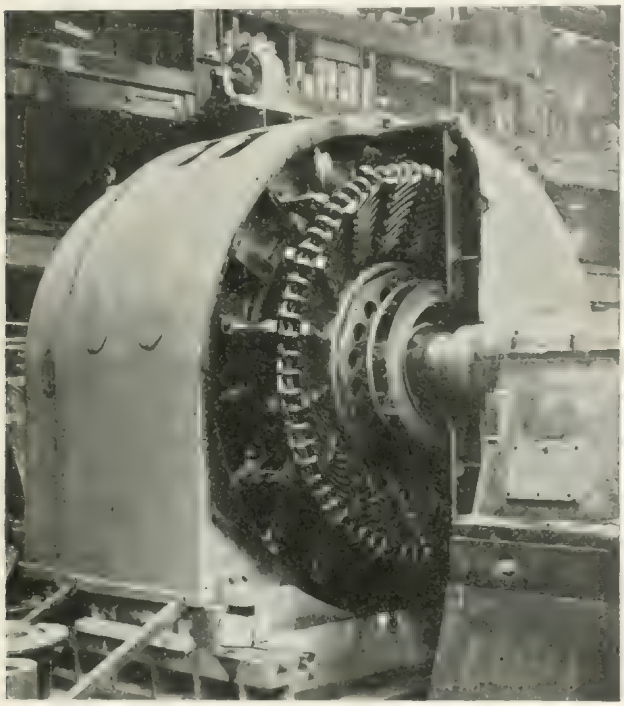

FIG. 7—SELF VENTILATED TURBO-GENERATOR
One-half end bell removed, showing inner partition wall and fan.

Various modifications of this scheme are possible and have been tried; first, with the addition of axial openings in the rotor; second, with the air admitted to a part of the outer diameter of the stator punchings and forced through radial ducts down towards the rotor and thence allowed to return to the outer diameter, the path of the air being twice across the depth of the punching; third, with the air admitted to a part of the outer diameter of the stator punchings, say, the upper half of the frame, and allowed to pass down through the punchings to the bottom of the machine and out.

According to the second general method, the air is passed through axial holes in both the stator and the rotor and discharged through a central duct into the frame. A possible modification of this second method is to sub-divide the core into, say, four sections and to supply air to the central duct through a passage provided outside of the stator iron, the outlet from the central ducts being through axial holes both ways from the center. This latter scheme has not been developed to any considerable extent commercially, as it is quite liable to produce uneven circulation of air and consequent unequal distribution of temperature.

Both these principal schemes of ventilation have their advantages, and there is a great deal of difference of opinion amongst designers as to their relative merits. The latest practice, however, especially for large machines, seems to favor the axial system for two principal reasons:—First, in the large units at the higher speeds it is difficult to provide the necessary cross-section of path to carry all of the air necessary to ventilate the machine through the air-gap in parallel, perhaps, with axial slots in the rotor, without making the air-gap unduly large and thus handicapping the design; second, the radial ventilation scheme takes up more length along the shaft than the axial scheme and so increases the space between the journals, reduces the stiffness of the rotor construction, and lowers the critical speeds. It is very desirable to keep the critical speed well above the running speed as the smoothness of operation depends upon this factor. The necessity for keeping the span between the bearings as short as possible is the reason why it is often necessary to provide separately driven external fans for ventilating the units of large output at 1 500 and 1 800 r.p.m.

There are, however, secondary advantages of the separate fan which are well worth considering. First, might be mentioned the reduction of noise due to the lower tip velocity of the separately driven fan. This reduction of noise may become an important factor where large units are to be located in cities. Second, the use of a separate fan permits the air for cooling the generator to be supplied to the intake at a much higher velocity than for a unit with self-contained blower, since it is essential not to restrict the intake to any fan. Where the air has to be brought to turbo-generators in ducts, the problem of obtaining sufficient cross-section becomes increasingly difficult with increase in capacity of the generator and a separate fan with higher velocity of air to the generator end bells would often be necessary for this reason alone.

In case of machines with self-contained blower mounted directly on the shaft it is necessary to limit

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*See article by Mr. B. G. Lamme in the JOURNAL for Feb., 1913, p. 12.

the maximum velocity of the air entering the end bells. It is customary to specify that the intake be of sufficient size to supply not less than four cubic feet of air per minute per kilovolt-ampere of rated capacity of the generator, with a pressure drop not exceeding one-quarter ounce per square inch from

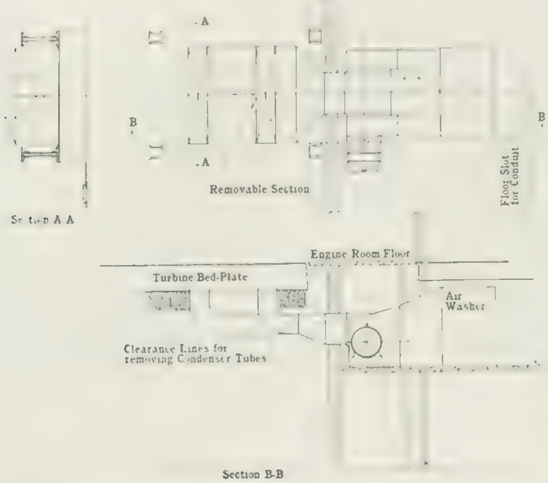

FIG. 8—VENTILATING SYSTEM USING SEPARATE FAN
This system handles 60 000 cu. ft. of air per minute.

the outside air to the base of the generator. The velocity of the intake air corresponding to the above pressure drop varies somewhat with the length and the section of the duct. It is usual to allow a velocity of 1 000 feet per minute for volumes of air up to 10 000 cubic feet per minute, 1 200 feet per minute velocity up to 30 000 cubic feet per minute, and 1 400 feet per minute velocity up to 45 000 cubic feet per minute. By the use of special fans it is possible in some cases to raise the limit of pressure drop, and in a few instances ducts have been built requiring a drop as great as one and one-half ounces. Such a case, however, is the very special one and, in general, would be considered undesirable.

On the other hand, the use of the separate fan permits of much higher velocities for the air. As an example might be cited the case of a fan handling 60 000 cubic feet of air per minute. The air velocities for this installation were 2 200 feet per minute at the fan intake, 3 500 feet per minute at the discharge orifice of the fan and 2 500 feet per minute minimum velocity in the duct leading to the generator, the arrangement being as shown in the diagram Fig. 8.

An increase in the use of ducts for admitting air is to be expected, since the use of air filters is the next rational development in connection with large machines, it being obviously less expensive to keep the dirt out of a machine than to remove it after it has collected. Especially is this true if one considers the value of the lost time while the unit is being cleaned and the increased factor of safety in favor of the machine operating with clean air.

The best method of removing dirt from the air is that of washing it out with water. There are several air-conditioning outfits on the market at the present time, all of which are substantially the same in principle. A chamber is provided in which water in the form of mist or spray is mixed with the air passing through the chamber. The dirt and soluble matter are removed from the air by the water and are carried off to a filtering plant where they are removed from the water which is recirculated. The air when leaving the chamber strikes up against surfaces called eliminators whose function it is to remove the unevaporated moisture. Tests have shown two distinct gains in air thus treated:—First, it has been conclusively proven that approximately 98 percent of all dirt and solid matter is removed from the air; and second; the air itself is reduced in temperature from three to ten degrees C., depending on its initial temperature and humidity. A typical installation of an air washer, a ventilating fan and inlet ducts is shown in Fig. 8.

In this particular installation the power house already existed and and some of the space limitations are indicated in the figure, where the location of existing walls and girders are shown, as well as the limit lines for the removal of tubes from the condensers. It will be noted that the air outlet at the bottom of the generator is restricted and, in fact, a

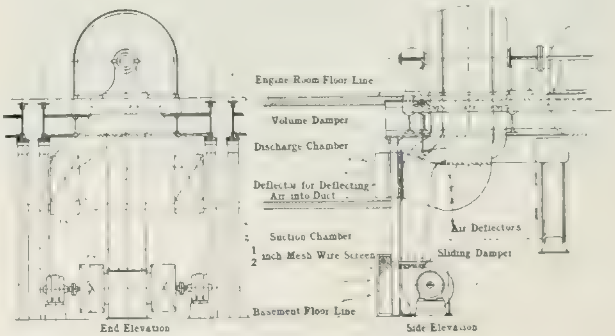

FIG. 9—TYPICAL VENTILATING ARRANGEMENT FOR STATIONS OF LARGE CAPACITY
Showing the use of an outlet as well as an inlet duct.

part of the discharged air was allowed to escape at the top of the machine. A second installation is shown in Fig. 9, in which an outlet duct is supplied as well as an inlet duct. This latter construction is the usual arrangement adopted for modern stations of large capacity.

Conditioning Air for Generator Ventilation

W. W. Stevenson

THE FOLLOWING article describes the air-conditioning apparatus used for cooling and cleaning the air supplied to two 6 000 k.v.a. turbo-generators. At the present time the apparatus is new, having been in service only a few months, but on account of the fact that it is steadily maintaining the advantage which was very apparent from the beginning, it is believed that its record is established.

TWO 6 000 kilovolt-ampere generators supply power for manufacturing purposes in a plant where the heaviest loads always occur during the day time and where the average load throughout the year is fairly constant. Outside temperatures as high as 90 to 95 degrees F. are common during summer months, and zero weather is not uncommon in winter, while the humidity varies over a wide range. Moreover the extreme of high temperature and dry air occurs during the day when the load is greatest, and that of low temperature and air most nearly saturated occurs at night when the load is lightest. These are clearly not the most favorable conditions for supplying air for cooling generators, although the average outside temperature throughout the year is somewhat lower than the average temperature of inside air. These, among other considerations, resulted in the decision to use inside air at an average temperature of about 70 degrees F. instead of air drawn from the outside. Two air washers serve the generators. and are connected thereto by a single duct, allowing the use of either or both washers on either or both generators.

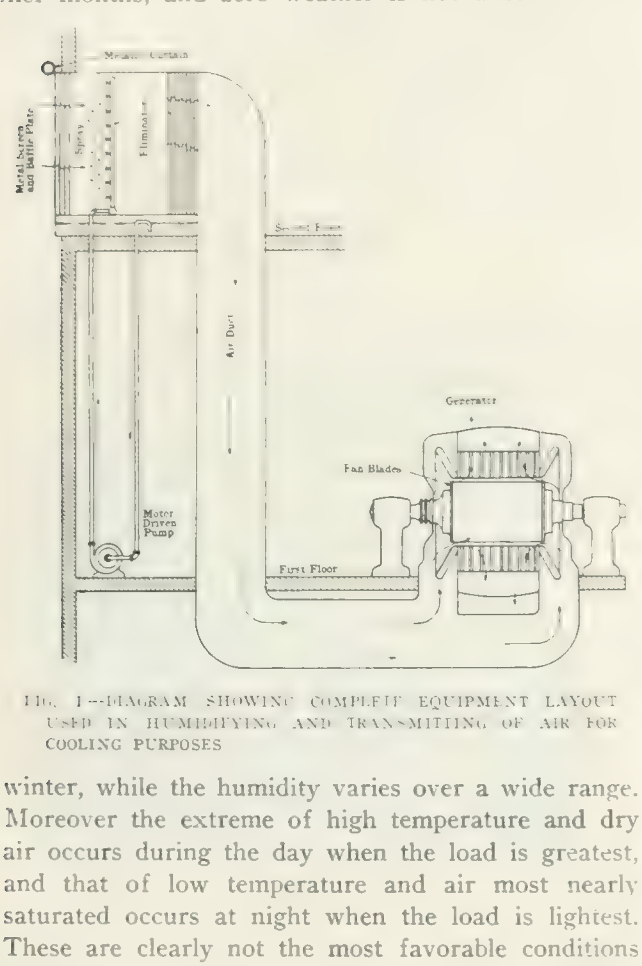

FIG. 1—DIAGRAM SHOWING COMPLETE EQUIPMENT LAYOUT USED IN HUMIDIFYING AND TRANSMITTING OF AIR FOR COOLING PURPOSES

Cooling the air is only one of the necessary operations to be performed, the other being to remove dust particles which would otherwise be carried into the generator to lodge there. It is necessary under any conditions to remove the end bells occasionally and thoroughly clean the windings of the machines, but this means an outlay of considerable time and expense, making it very desirable to have the intervals between cleaning as long as possible. In this case where it was formerly necessary to shut down and clean the generator once in four to six months at least, the addition of the air washing outfit makes it unnecessary to clean them more often than once in a year or over, giving, in consequence, a decided saving in operator's time and period of shut-down. The spray of water in the washers is very effective as an air washer, but is is by no means perfect, as particles of an oily nature or oily vapors, which are not readily removed in the washer, are constantly floating in the air. This, of course, constitutes only a small part of the impurities which would otherwise pass into the generators, as is evidenced by the large amount of sediment which is periodically removed from the settling tank.

Referring to Fig. 1, air is drawn through the washers by fan blades on the generator rotor and forced out through ventilating slots in the armatures as indicated. It enters the washer through expanded metal screens and passes through baffle plates which serve to check the spray of water which is directed against them. Rolls of metallic curtains can be pulled down to close off the intake in case a washer is out of service for repairs or otherwise.

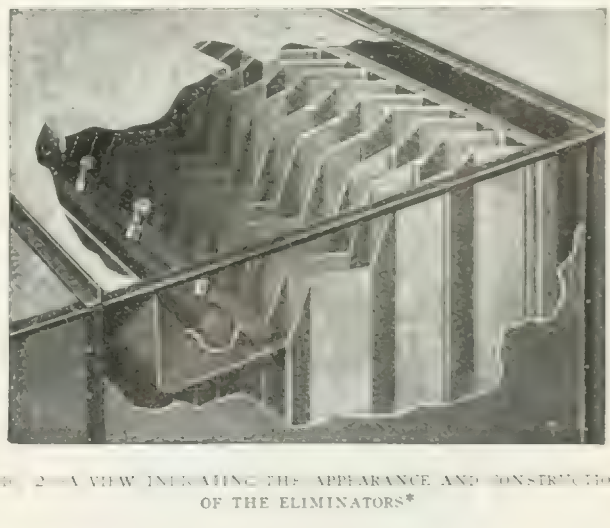

FIG. 2—A VIEW INDICATING THE APPEARANCE AND CONSTRUCTION OF THE ELIMINATORS*

The spray of water during normal operation is carried backward by the inrushing air until it comes into contact with another set of baffle plates called eliminators. These eliminators, Fig. 2, free the air of all water which might otherwise be carried into the air-duct unabsorbed. Provision is made for flooding the baffle

*Figs. 2 and 5 furnished through the courtesy of the Carrier Air Conditioning Company, of New York City.

plates to insure a wet surface for contact with the air and to wash away any accumulation of dirt.

The spray nozzles used are very simple and effective, the spray being produced by the whirling action of water led tangentially into a circular cham-

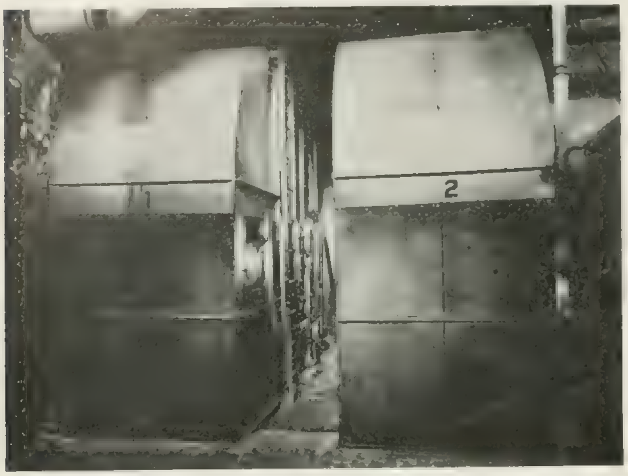

FIG. 3—REAR VIEW OF HUMIDIFIERS SHOWING AIR DUCTS LEADING FROM HUMIDIFIERS TO TURBINE ROOM BELOW

ber from which it is expelled through a circular orifice at the center. Fig. 4 shows the mechanical construction of this general type of spray nozzles. As the spray nozzles are very essential features of the washers it is important that they do not become clogged or otherwise demand attention. Ample provision is made to prevent clogging by using strainers in the pump discharge line near the washers and by preventing sediment from entering the pump suction. In another type of apparatus provision is also made for flooding the nozzles. The pumps shown in Fig. 5 are located on the turbine room floor below the washers, and maintain a pressure of about 35 pounds at the spray nozzles. Each has a capacity sufficient to supply both washers, although at a slightly reduced pressure. The bodies of the washers are provided with glass doors, and incandescent lamps inside, making it an easy matter to examine the sprays or other vital parts at any time. Pressure gauges and permanent thermometers are provided so that the washers can be operated to the best advantage.

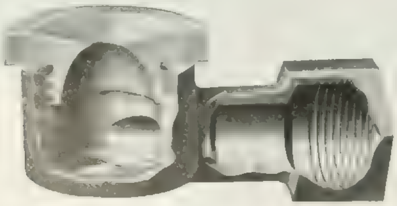

FIG. 4—SECTIONAL VIEW OF HUMIDIFIER SPRAY NOZZLE

It is by no means a difficult matter to obtain air almost entirely saturated after passing through the washers, but extreme weather conditions, lack of pressure at the spray nozzles, and insufficient flooding of the eliminators may combine to reduce the relative humidity to 95 percent or lower. The entire process of humidifying is completed in slightly over one second, this being the time required for the air to pass through the apparatus. During the passage through the washer there is little or no appreciable drop in air pressure.

The ducts connecting the washers and generators are provided with several doors at which the air can be examined at any time, on its passage to the generators, to determine its temperature, humidity or cleanliness. The connection to the generators, as shown in Fig. 1, is at the bottom of the end bells, where the air finds its way through and around the ends of the armature coils to the fan blades, whence it is forced into the air-gap and out at the ventilating ducts in the laminations.

Since the speed of the fan on the generator rotor is constant, it is fairly accurate to assume that equal volumes of air pass the washer in a certain time, under all conditions of loads. Also, since the water used for humidifying and cleaning is circulated over and over again, only enough being supplied to replace that

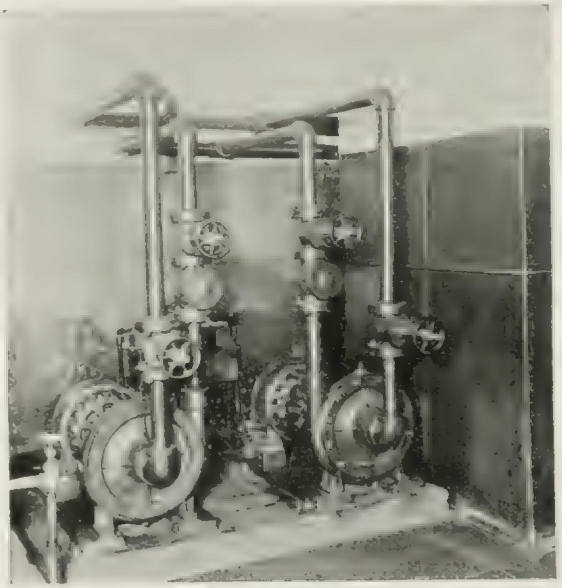

FIG. 5—MOTOR-DRIVEN CENTRIFUGAL PUMPS USED FOR CIRCULATING WATER THROUGH THE HUMIDIFIERS

carried away in the form of water vapor, we may, for mathematical simplicity, consider the temperature changes in the washer due entirely to changes in humidity. Assuming, therefore, a cubic foot of air at 70 degrees F. and 35 percent saturated, we may represent its temperature and humidity by the point *A*, Fig. 7.* Passing this air through the washer its relative humidity increases along the line *AB*, due to the addition of moisture, until at *B* it has a relative humidity of 95 or, in other words, is 95 percent saturated; while its sensible temperature has decreased to 55 degrees. Assuming further that the point *B* rep-

*In plotting the values of temperatures, humidity, total heat and all the properties of moist air as they appear in Fig. 6, free use was made of the psychrometric charts compiled by Mr. William H. Carrier, in Vol. 33 of the Transactions of the American Society of Mechanical Engineers.

resents the temperature and humidity of the air as it enters the generator, the line *BC* shows the decrease in relative humidity due to its rise in temperature in passing through the generator. In this case the air is shown leaving the generator at 130 degrees F. and 10 percent saturated, as indicated by the point *C*. Had the same cubic foot of air not been passed

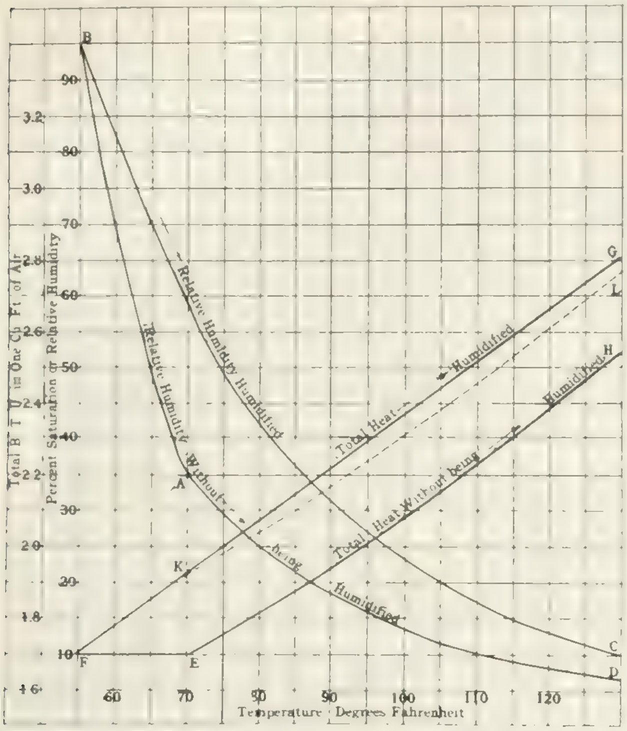

FIG. 6—CHART SHOWING RELATION BETWEEN RELATIVE HUMIDITY AND TEMPERATURE AND RELATION BETWEEN TOTAL HEAT AND TEMPERATURE

Indicating a complete heat cycle for a cubic foot of air in its passage through the humidifier and generator.

through the washer, the relations of its temperature and humidity would be indicated by the line *AD*.

Although there is no important mathematical significance in these changes, it is well to note that air as it enters the generators at the point *B* is not to be considered as carrying with it a quantity of water, but rather as a perfect mixture of air and water vapor. If for any reason a particle of water were to find its way into the generator, the tendency would be for the air to absorb it, as indicated by the rapid decrease in saturation along the lines *BC* and *AD*. It is to be further understood that the same weight of water in the form of water vapor in grains per cubic foot passes out at *C* as enters the generator at *B*, except for the slight variation of air volumes due to increase in temperature.

As the heat-carrying capacity of the air is the really important consideration, the same subic foot of air may be taken whose temperature and humidity is represented by the point *A*, Fig. 6, and it will be noted that its total heat above 32 degrees F. is 1.7 B.t.u., as indicated by the point *E*. It was assumed in the beginning that no heat was added by the water, as it requires only a few grains to completely saturate a cubic foot of air, and since there is no heat transfer involved in adding water vapor to air when both air and vapor are at the same temperature, a horizontal line from *E* to *F* will represent the passage of the air through the humidifier. The ability of the mixture to contain heat has increased during the process until, when its temperature is again brought up to 70 degrees F., its total heat has increased to 1.9 B.t.u., as represented by the point *K*. The line *FKG* shows the increase in total heat per cubic foot, with increase in temperature, as the air passes through the generator. Had it not been humidified its increase in total heat would be indicated by the line *EH*.

The line *KL* is an arbitrary one drawn from the point *K*, parallel to *EH*, to show that the difference in the heat carrying capacity of the air before and after humidifying gradually increases as the temperature increases. The two conditions governing this characteristic are temperature and relative humidity. If the relative humidity were constant, the heat carrying capacity would rise very rapidly with increase in temperature. On the other hand, increase in temperature decreases the weight of a unit volume of air which, taken alone, would mean a decrease in heat carrying capacity. The two combine in a way such as to give the values as shown on the curve.

The advantage of the humidifier or washer from this point of view may be summed up in the statement that if the generator is carrying a load such that the air leaving it is at a temperature of 130 degrees F., then 32 percent more heat is being carried away than would be carried away had the air not been humidified. The 32 percent is the ratio between the lines *HG* and *CH*. The advantage from the standpoint of the operating man is that for the same temperature rise he can increase the load which the generator can carry when using humidified air above that when using the same air not humidified. It is not within the province of this article to state the theoretical in-

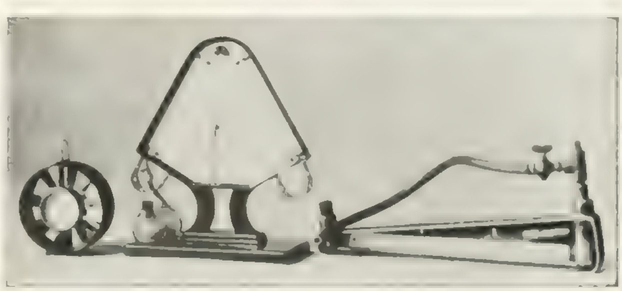

FIG. 7—APPARATUS USED IN DETERMINING THE VOLUME, PRESSURE, TEMPERATURE AND HUMIDITY OF AIR

crease in capacity obtainable in this way. Suffice it to say that the electrical equivalent of the heat value *HG* under actual operating conditions, is 103 kilowatts on each of the 6 000 k.v.a. machines described. This means that additional load can be carried, up to the point where the additional losses caused by this load amount to 103 kilowatts, with the same ultimate temperature.

The Production Problem in the Foundry and Machine Shop Industry

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Industrial Engineering Company, Pittsburgh, Pa.

THE FOLLOWING ARTICLE will be especially interesting to men in the operating and new business departments of electric power companies. It shows the economic situation now confronting the foundry and machine shop industry and how purchased power affords a means of solving many of their problems.

MANUFACTURERS operating foundries and machine shops have the same difficult problems before them that exists in nearly every industry, namely, to keep the increase in the capital account consistent with the increase in production. In the United States during the past ten years, the capital required has increased at a greater rate than the production. The result has been a considerable reduction in the profits. For instance, in 1903 the profit upon the capital averaged 17 percent, while in 1913 it averaged only 11 percent. These figures represent the gross profit upon the capital and do not include the fixed charges the industry has to carry. If these charges were deducted, the profit would be much less. So the most important question is—how to increase the production with but a slight increase in the capital. A greater output will produce larger profits. The total value of the product will not only be increased but the cost per unit manufactured will be less, and therefore the profit will be greater.

TABLE I—THE FOUNDRY AND MACHINE SHOP INDUSTRY—ALL ESTABLISHMENTS

Item No.	Item	1903	1913	Percent Increase or Decrease
1	No. establishments	11 180	13 414	20. +
2	Capital	$806 902 401	$1 543 558 607	91.5 +
3	Primary horse-power	463 231	889 212	96. +
4	Value of products	$833 627 841	$1 281 053 730	53.8 +
	Cost Items			
5	Materials	$371 385 000	$ 552 431 000	48. 7+
6	Wages	221 553 000	328 369 000	46. +
7	Salaries	41 991 000	100 173 000	138. +
8	Miscellaneous expenses	57 295 000	129 336 000	125. +
9	Total cost	695 224 000	1 110 309 000	59. +
10	Total profit	137 401 000	170 743 000	24.5 +
11	Percent profit on capital	17	11	54.5 —
12	No. wage earners	436 293	542 587	24.3 +
13	No. salaried employees	35 743	77 794	117. +
14	Av. salary per sal. emp.	$1175	$1287	9.65+
15	Wage per wage earner	515	605	17. 4+

The object of this paper is to show:—

1—The general condition of the foundry and machine shop industry of today.
2—A way to obtain a greater production.
3—The effect of increased output upon the profits.

The data pertaining to this industry is worked up from the United States census reports. It includes all industries operating foundries and machine shops, excepting those manufacturing a distinctive product, such as cash registers, calculating machines, sewing machines, automobiles, electrical apparatus, etc. The data pertains more specifically to general jobbing foundry and machine shops and those manufacturing products such as steam and gas engines, gas and water meters, bells, hardware, plumbers' supplies, saddlery, hardware, steam fittings, structural iron work, etc.

GENERAL CONDITIONS

The general conditions of the industry as a whole is indicated by Table I, which includes the total number of establishments, capital, value of products, cost to manufacture and general details. This table shows that the number of establishments (item *1*) increased 20 percent and that competition in all lines became greater. The value of the products in 1913 exceeds one and one quarter billion dollars, this industry taking second place in the value of its products. It is interesting to note that wages (Item *15*) were increased 17 percent in ten years while salaries, Item *14*), were increased only 9.65 percent.

Table II is an analysis of Table I, the details being worked out to show the number or value per establishment. It shows that the capital increased 59 percent in ten years and the primary horse-power increased 63 percent. The latter figure shows that most of the new capital was spent for improvements. The increase in the primary horse-power denotes that more and heavier machinery was installed. To drive this additional machinery required increased capacity in power plants. Such improvements are expensive and must have taken much of the new capital.

TABLE II—FOUNDRY AND MACHINE SHOP INDUSTRY ON A PER ESTABLISHMENT BASIS

Item No.	Item	1903	1913	Percent Increase or Decrease
1	Capital	$72 174	$115 070	59. –
2	Primary horse power	40.5	66	63. -
3	Value of products	$74 475	95 501	28 2 -
	Cost Items			
4	Materials	$33 219	$41 183	24. +
5	Wages	20 085	24 479	21.9+
6	Salaries	3 756	7 466	99. +
7	Miscellaneous items	5 120	9 642	88. +
8	Total cost	62 180	82 770	33. +
9	Total profit	12 295	11 371	3.5+
10	Percent profit on capital	17	11	54.5—
11	No. wage earners	39	40	2.5+
12	No. salaried employees	3	6	100 +

The value of products increased 28 percent and the capital 59 percent. This shows conclusively that in the average establishment the capital increased faster than the production. The resulting effect of this is shown in the percent profit which decreased from 17 percent in 1903 to 11 percent in 1913. Although the production increased 28 percent, the number of wage earners increased only 2.5 percent, indicating that the manufacturers installed machinery which was more efficient and required less labor.

The results of the complications of modern business are shown in that the number of salaried em-

ployees, (Item *12*), increased 100 percent; as the business became greater it became more complicated and needed more office help to transact it.

Table III gives the details from the former table for each $100 worth of goods manufactured per year. The evil of increasing the capital at a greater ratio than the production is clearly shown. For instance, in 1903 there was $97 capital invested for each $100 worth of goods produced per year; ten years afterwards $120.48 capital was needed to produce the same output. In other words, the earning power of the capital became less.

Although Table I shows that the average wage earner receives more money than formerly, nevertheless, wages per unit of production decreased 5.2 percent. There are two reasons for this—more efficient machinery and more intelligent labor. The cost of materials decreased 3.4 percent.

In Table IV is shown the profit earned upon the capital. In 1903, $103 worth of goods was produced for each $100 capital invested and in 1913 only $84 worth was produced. The effect of the ratio of capital to production is shown in the gross profit, which decreased 49.3 percent.

TABLE III—FOUNDRY AND MACHINE SHOP INDUSTRY ON A $100 VALUE OF PRODUCT BASIS

Item No.	Item	1903	1913	Percent Increase or Decrease
1	Capital	$97.00	$120.48	24.2
	Cost Items			
2	Materials	44.60	43.12	[illegible]—
3	Wages	26.96	25.63	5.2—
4	Salaries	5.04	7.82	[illegible]
5	Miscellaneous items	6.88	10.09	46.7
6	Total cost	83.48	86.66	3.8
7	Total profit	16.52	13.34	[illegible]—
8	Percent profit on capital	17	11	54.5—

HOW TO INCREASE PRODUCTION

A number of manufacturers have been able to increase their production through "Scientific Management," that is, they obtain a greater output by increasing the individual workman's efficiency and through a shop system arranged for their peculiar needs. The principal disadvantage of this method is that it takes several years to train the men and get the system into working order, all of which is very expensive. Another serious weakness of this method is that during business depressions, or when there is a plentiful labor supply, the average shop efficiency will be high, while, when business is good and labor scarce, the shop efficiency will be lowest. The reason for this is that when there is an abundant supply of labor, the management can be very careful in the selection of their men, so that the personnel of the organization will be high. These men can be taught new methods and a high shop efficiency can be obtained. When business conditions are good, labor is usually scarce; frequently it is difficult to keep the present employees. At such times the manufacturer cannot be so choice in the selection of laborers and often has to take whoever is available. These men will not assimilate the new ways, and in a short time it will be found that the older employees are gradually slipping back to their former ways, until finally the efficiency of the entire shop is reduced. This is characteristic of any system that depends upon the human element.

A method that will allow the manufacturer to maintain a high shop efficiency during both good and dull business periods would certainly be much more attractive. Such a method must deal with the physical equipment and conditions of the shop first and human element afterwards. Remarkable results can be obtained by treating with the physical equipment and conditions of the shop. The machinery should be located so as to allow the greatest ease in the handling of the material and the shortest possible routing. Power should be applied to the machines so that those requiring variable speed can be operated at a range of speeds in a series of small steps, and the constant speed machines so as to always operate at the maximum speed. Opportunities in this line exist in the majority of machine shops.

TABLE IV—FOUNDRY AND MACHINE SHOP INDUSTRY ON A $100 CAPITAL BASIS

Item No.	Item	1903	1913	Percent Increase or Decrease
1	Value of product	$103.19	[illegible]	[illegible]
	Cost Items			
2	Materials	[illegible]	[illegible]	[illegible]
3	Wages	[illegible]	[illegible]	[illegible]
4	Salaries	[illegible]	[illegible]	[illegible]
5	Mis. expenses	7.10	[illegible]	[illegible]
6	Total cost	86.15	[illegible]	[illegible]
7	Total profit	17.04	[illegible]	[illegible]
8	Percent profit on capital	17	11	[illegible]

Before proceeding further it would be well to illustrate the above points. The following example. Table V, shows the speed increments obtained by belt drive on a 10 foot Niles boring mill. The range of speeds is from 0.6 to 45.5 r.p.m. in 14 steps of 36 percent increase per step. There is also a large gap between the back gear and the open drive speeds. the increase being 100 percent.

TABLE V—SPEEDS WITH BELT DRIVE—ON A TEN FOOT BORING MILL

Cone	Back Gear	Open Drive
1	0.63	[illegible]
2	[illegible]	10.3
3	1.2	14.
4	[illegible]	18.5
5	2.0	[illegible]
6	2.7	[illegible]
7	[illegible]	[illegible]

By applying an adjustable speed motor to this machine a saving of several hours per day could be effected on the class of work going through at the time the tests were made. The speeds to be obtained are shown in Table VI, varying from 1.1 to 20 r.p.m. in 32 steps of 10 percent increase per step. One can readily see that with this arrangement the output of the machine could be increased.

On machines operating at constant speed there are frequently splendid opportunities for betterment. For instance, in one machine shop eight Prentice

drill presses were operated from one line shaft. These presses all worked upon the same kind of material and operated continuously for 10 hours each day. The driving pulleys upon the shaft were all the same size and the driven pulleys upon the presses were all of the same dimensions; and all were supposed to operate at 285 r.p.m. Table VII shows the speeds of each press under working conditions. The

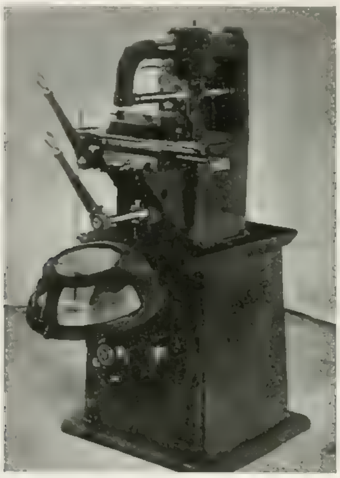


FIG. 1—MOTOR-DRIVEN MILLER

Controller gives 16 speeds as compared with eight available by belt drive.

difference in speed was due to the different kinds of belts used and their condition, which caused an abnormal slippage. This manufacturer increased the output of these drills 20 percent by installing individual motors and gearing directly to the machines.

Applying motor drive to a factory will not necessarily in itself increase production. To get the best possible results, an analysis of the operating results of each machine is necessary, with especial regard to the cost or tools and of labor. Standard practice does not always cover special operations in a particular shop where a tool is called upon to perform operations on special work.

Power has an important bearing upon the production of a factory. The source of power should

TABLE VI—SPEEDS WITH MOTOR DRIVE—TEN FOOT NILES BORING MILL

Cone Step	Back Gear	Open Drive
1	1.10	5.
2	1.21	5.5
3	1.32	6.
4	1.45	6.6
5	1.60	7.3
6	1.75	7.9
7	1.95	8.7
8	2.10	9.5
9	2 30	10.4
10	2.53	11.5
11	2.77	12.6
12	3.04	13.8
13	3.34	15.2
14	3.66	16.7
15	4.01	18.2
16	4 40	20.0

be such that at all times it is possible to operate all the machines at their maximum capacity. This means that the power must be both constant and sufficient so that the speed of the machines will not fluctuate with the variations in the loads.

A great number of foundry and machine shops throughout the United States are now operated by purchased power, their owners having found it more economical to purchase power than to produce it themselves. They also found the speed conditions were improved due to a more uniform voltage. Another decided advantage in favor of this power is that it allows extensions and additional machinery to be installed at a minimum of expense, the only addi-

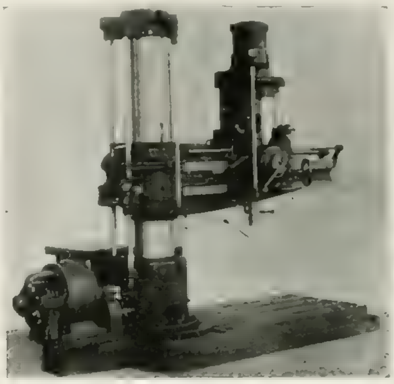


FIG. 2—RADIAL DRILL DRIVEN BY A FIVE HORSE-POWER VARIABLE-SPEED MOTOR.

This drill allows 16 speeds forward and six reverse.

tional cost being the small amount for the new motors. Today 23.9 percent of all power used in this industry is central station service. Table VIII shows the total amount and the kind of power used.

TABLE VII—TESTED SPEEDS OF BELT—DRIVEN DRILL PRESSES

Machine No.	R.P.M.—Driven Pulley
1	270
2	260
3	262
4	205
5	175
6	210
7	210
8	270

A rate commonly quoted for this kind of industry by the power companies in the Pittsburgh district, is $15 per kilowatt per year for the maximum demand, plus $0.015 per kilowatt-hour for the current

TABLE VIII.—POWER IN FOUNDRIES AND AND MACHINE SHOPS IN 1913.

Kind of Power	Horse-power in use	Percent of Total Power
Steam engines............	546 206	61.4
Gas engines........	96 966	10.9
Water wheels (and other power).........	21 456	2.4
Rented power............		
Electric motors.........	212 884	23.9
Other power	11 700	1.4
Total power............	889 212	100

consumed. Table IX contains a list of 22 foundries and machine shops now buying their power. The data contained in this table was obtained by tests made in each factory. This table shows the details pertaining to the power, the cost of power per horse-power-hour, and what saving would be effected by using central station service at the above rate. This rate upon a horse-power basis would be $11.20 per

horse-power per year for the maximum demand, plus \$0.0112 per horse-power-hour for the current used. It is interesting to note that in only one instance, (Item 7), was it cheaper to operate an isolated plant.

The principal reason why many manufacturers have difficulty in comparing their own power costs with the cost of purchased power is because they do not know the exact amount of power being generated, nor the quantity that would be needed if power were produced. Table X contains a list of 42 foundries and machine shops operated by purchased power. The last column in this table shows the number of kilowatt-hours consumed per year per horse-power of motors installed.

TABLE IX—FOUNDRY AND MACHINE SHOP INDUSTRY—COMPARATIVE COST OF POWER

	Isolated Plant Power						Purchased Power Rate \$11.20 per Hp. Max. Dem. plus 1.12c per Hp.—Hr.		
No.	Price of Fuel	Hp. of Eng.	Max Dem Hp	Per-cent Load Factor	Hp.—Hours Consumed per Year	Cost per Hp. Hour Cents	Cost per Hp.—Hr. Cents	Saving per Hp.—Hr. Cents	Saving per Hp.—Hr. Percent
	FOUNDRIES ONLY Group (A)—Gas Engines up to 50 Horse-Power								
1	20c-G	50	40	24	97 800	2.5	1.58	0.92	36.7
	Group (B)—Gas Engines from 51 to 100 Horse-Power								
2	20c-G	60	40	6.8	35 600	4.69	2.37	2.32	49.5
	Group (C)—Steam Engines from 51 to 105 Horse-Power								
3	\$1.60-C	60	50	13.7	71 000	4.09	1.91	2.18	53.2
4	4c-G	60	70	30.4	160 000	1.8	1.61	0.19	10.5
5	\$2.35-C	100	85	16	140 000	3.4	1.8	1.6	47.
	Average cost					3.3	1.77	1.53	46.3
	Group (D)—Steam Engines from 201 to 500 Horse Power								
6	\$2.25-C	475	300	14.	582 000	2.4	1.69	0.71	29.6
	Group (E)—Ga3 Engines from 501 to 1000 Horse-Power								
7	$12\frac{1}{2}$c-G	773	400	23	1 558 000	1.2	1.4	0.2	16.6
	MACHINE SHOPS ONLY Group (A)--Steam Engines up to 50 Horse Pewer								
8	\$2.35-C	50	35	19	83 400	2.2	1.59	0.61	27.7
9	\$2.35-C	50	40	16	70 000	3.4	1.76	1.64	48.2
10	\$2.35-C	50	50	19	83 400	3.3	1.89	1.49	45.2
11	\$2.35-C	50	50	19	83 400	3.9	1.89	2.01	51.5
	Average cost					3.6	1.8	1.8	50.0
	Group (B)—Steam Engines from 51 to 100 Horse-Power								
12	10c-G	56	50	8.5	41 700	5.6	2.46	3.14	56.2
	Group (C)—Steam Engines from 101 to 200 Horse-Power								
13	\$1.30-C	120	130	13	137 000	3.5	2.17	1.33	38.0
14	5c-G	125	125	56	615 000	1.3	1.3	......	.....
15	\$2.25-C	125	125	20	219 400	2.9	1.76	1.14	39.2
16	\$3.25-C	125	100	31	230 000	2.78	1.6	1.18	42.4
17	\$2.00-C	150	130	19	250 000	2.9	1.7	1.2	41.4
18	\$2.00-C	150	125	16	211 000	2.9	1.77	1.13	39.0
	Average cost					2.71	1.7	1.01	37.2
	Group (D)—Steam Engines from 201 to 500 Horse-Power								
19	\$2.25-C	250	480	17	373 000	2.9	2.56	0.34	11.7
20	\$2.00-C	400	200	6	211 000	4.7	2.18	2.52	53.7
21	\$2.35-C	485	300	16	680 000	2.4	1.61	0.79	32.9
	Average cost					3.0	2.11	0.89	29.7
	Group (E)—Steam Engines over 1000 Horse-Power								
22	\$2.35-C	2400	1600	14	2 940 000	2	1.73	0.27	1.35

THE RESULT OF INCREASING PRODUCTION

In practically every case in which a manufacturer has changed from line shaft drive to purchased power, with a proper application of motors, there has been an increase in the production, a 25 percent increase being by no means unusual. Using the data contained under the column headed 1913, Table II, as a working basis, let us see what effect a 25 percent increase in the production would have upon the gross profits. The value of the product was \$95 501; an increase of 25 percent would make this \$51 478. The wages, salaries and miscellaneous expenses would remain the same, hence the cost of production would be as follows:—

TABLE X—FOUNDRIES AND MACHINE SHOP—POWER CONSUMED PER HORSE-POWER PER YEAR

Item No.	Horse-power of Motors	Kind of Drive	Total No. of Motors	Kw-Hr. Consumed per year	Kw-Hr. Consumed per year per Hp. Installed
1	25	Group	2	12 [illegible]	503
2	27.7	Semi—G	7	15 100	541
3	30.5	Group	4	16 000	524
4	40.0	Group	3	49 900	1248
5	47.5	Group	5	65 400	1365
6	51	Individ.	12	11 200	208
7	58	Group	6	17 220	300
8	58	Group	4	111 800	1930
9	59.2	Individ.	7	39 100	647
10	82	Semi—G	7	110 000	1335
11	82	Semi—G	5	67 000	[illegible]
12	97.5	Individ.	5	26 600	276
13	164.5	Semi—G	14	[illegible]	637
14	182	Individ.	13	135 000	742
15	188	Individ.	11	[illegible]	322
16	190	Group	[illegible]	[illegible]	1140
17	242.5	Semi—G	[illegible]	297 000	960
18	281	Individ.	23	212 000	764
19	340	Group	10	422 000	1130
20	388	Individ.	25	309 000	800
21	445	Individ.	19	[illegible]	[illegible]
22	526.5	Individ.	25	297 000	566
23	585	Individ.	38	715 000	1220
24	1146.5	Individ.	56	614 000	535
		FOUNDRIES ONLY			
25	30.5	Group	4	16 000	524
26	58	Group	4	111 800	1930
27	82	Semi—G	7	110 000	1335
28	182	Individ.	13	135 000	742
29	281	Individ.	23	212 000	764
30	388	Individ.	25	309 000	800
31	526.5	Individ.	25	297 000	566
		MACHINE SHOPS ONLY			
32	27.7	Semi—G	7	15 100	541
33	40	Group	3	49 900	1248
34	47.5	Group	5	65 400	1365
35	54	Individ.	12	11 200	208
36	58	Group	6	17 220	300
37	59.2	Individ.	7	39 100	647
38	97.5	Individ.	5	26 600	276
39	164.5	Semi—G	14	[illegible]	637
40	242.5	Semi—G	[illegible]	297 000	960
41	340	Group	10	422 000	1130
42	1146.5	Individ.	56	614 000	535

Materials	\$51 478
Wages	24 479
Salaries	7 466
Misc. Expenses	9 642
Total cost	93 065

The gross profit would be the difference between the value of the product and the cost of production which is \$26 311. To equip an establishment of this size so as to obtain these results would require an additional investment of \$6 000. The capital was \$115 070 which, plus the new investment, would make the total capital \$121 070. The gross profit (in percent) upon the capital would be:—

$$\frac{\$26\ 311 \text{ gross profit}}{\$121\ 070 \text{ capital}} = 21.7 \text{ percent gross profit}$$

The gross profit earned in 1913 was \$12 731; thus, a 25 percent increased output would increase the gross profits 106 percent, or instead of earning 11 percent upon the capital, as in 1913, the capital would earn 21.7 percent.

Installing motors in a machine shop will not necessarily increase production. As said before, each

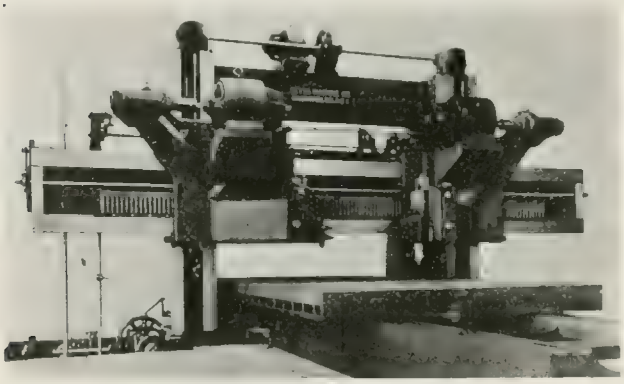


FIG. 3—A 10 BY 7 BY 18 FOOT PLANER

With special rail, carrying two cutting heads arranged so as to move at right angles to the platen. This arrangement permits machining the ends of any length of castings as well as surfaces which could not be reached with an ordinary planer.

application must be given individual study and a motor applied to meet the requirements of that particular machine. One point to guard against is the tendency to over-motor, that is, to install a motor of greater horse-power than necessary. Tests in any machine shop, excepting a few of those equipped dur-

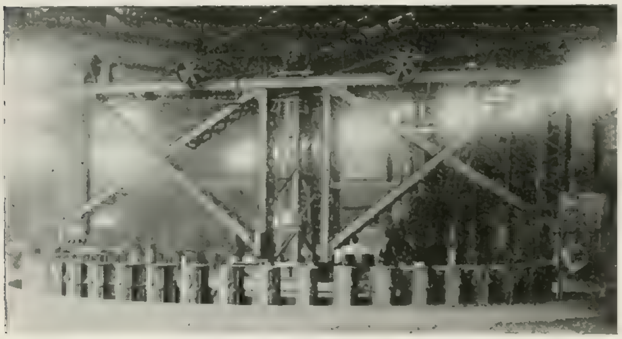


FIG. 4—PIPE CASTING MACHINE DRIVEN BY A 30 HORSE-POWER MOTOR

ing the past few years, will almost invariably show that they are over-motored anywhere from 50 to 400 percent; it is not at all unusual to find the latter figure. Table XI illustrates this point, and shows the condition found in a modern machine shop equipped with 25 motors totalling 445 horse-power. The plant was over-motored 99 percent or a total of 223.5 horse-power. This company invested \$5 000 more than was necessary for the equipment, and their power consumption was considerably more than it should be, due to the poorer operating efficiencies.

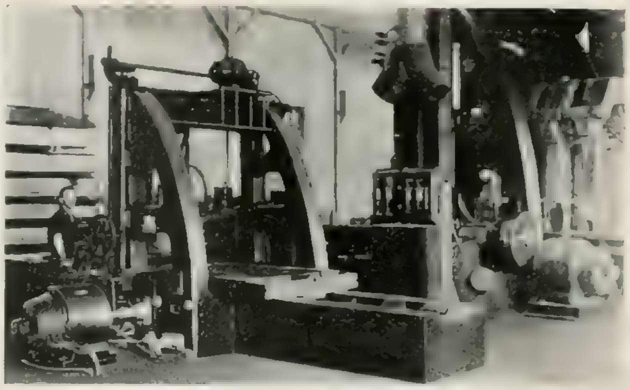


FIG. 5—PLANERS EQUIPPED WITH REVERSING MOTORS AND AUTOMATIC UNIT-SWITCH CONTROL

A seven foot planer driven by a 20 horse-power motor and a 10 foot planer driven by a 35 horse-power motor.

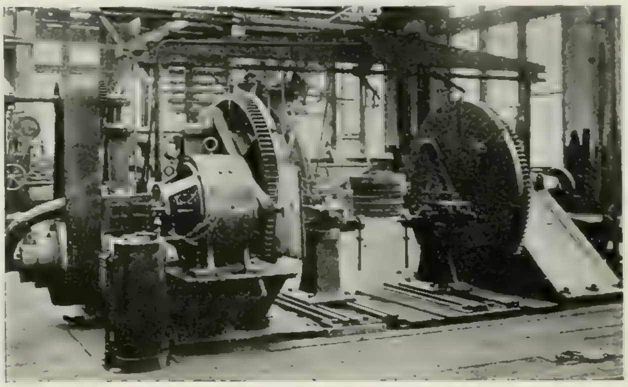


FIG. 6—AN 84 INCH WHEEL LATHE

Driven by a 35 horse-power variable-speed motor replacing the former installation of belt drive.

TABLE XI—OVER-MOTORING OF A MACHINE SHOP

Item No.	Apparatus Driven	Hp. of Motor in Use	Tests Max. Hp 10 min.	Showed Average Hp 10 min.	Size Motor Recommended	Percent Over-Motored
1	Line shaft	20	18	9.8	15	33.3
2	Line shaft	30	27.3	12.0	20	50.0
3	Line shaft	40	35.5	28.8	20	33.3
4	Planer	15	21 8	10.0	15	
5	Slotting machine	5	1.7	1.6	2	150.0
6	Planer	20	4.5	2.2	3	565
7	Boring mill	10	11.0	8.2	10	
8	Small pump	0.5	0.25	0.25	0.5	
9	Line shaft	30	21.2	15	15	100
10	Line shaft	30	10.0	8.5	10	200
11	Jack shaft	10	3.8	3.1	5	100
12	Hack saw	5	3.85	3.1	3	66.6
13	Boring mill	20	8.0	7.4	7 5	167
14	Milling machine	3	1.4	1.4	2.0	5.0
15	Milling Machine	3	3.35	3.1	3.0	
16	Drill press	7.5	6.2	5.4	7.5	
17	Milling machine	5.0	1.9	1.7	2.0	150.0
18	Planer	15.0	17.8	9.5	10.0	50.0
19	Heating fan	75.0	13.0	13.0	15.0	400.0
20	Heating fan	40.0	20.0	20 0	20.0	100.0
21	Milling machine	5.0	1.7	1.7	2.0	150.0
22	Fan	40.0	18.2	18.0	20.0	100.0
23	Lathe	10.0	4.0	3.4	5.0	100.0
24	Milling machine	3 0	1.1	1.1	1.0	200.0
25	Horiz. drill	3.0	1.5	1.2	2 0	50.0
	Total	445.0			223.5	99.0

The Engineering Evolution of Electrical Apparatus—IV

THE ALTERNATING-CURRENT GENERATOR IN AMERICA (Concl.)

B. G. Lamme

TURBO-GENERATORS

THE ADVENT of the turbo-generator has had a predominant influence on alternator design. After the turbo-alternator once became established commercially in this country, it quickly revolutionized conditions by driving the large engine-type alternators out of the field. The evolution of all electrical apparatus has been comparatively rapid, but that of the turbo-alternator has possibly exceeded anything else in the electrical field. This evolution therefore merits a fairly complete description.

The first turbo-alternators, built by the Westinghouse Company, were installed in the power plant of the Westinghouse Air Brake Company about 1898. There were three rotating armature machines of 300 kilowatts capacity, which ran at a speed of 3 600 r.p.m.,

FIG. 20—FIELD OF EARLY ROTATING ARMATURE TURBO-GENERATOR

giving 7 200 alternations per minute, or 60 cycles per second. They were coupled to Parsons turbines, built by The Westinghouse Machine Company. The Parsons Company in England had been building rotating armature alternators for a number of years, and the Westinghouse Company simply followed the Parsons' precedent. These first machines were operated for several years, but it was obvious, soon after their installation, that the rotating armature type of machine would not serve for general turbo-alternator purposes. It was evident that, for voltages even no higher than 2 200, the rotating armature construction, at the necessary turbo-generator peripheral speeds, would become almost impracticable. Attention therefore was soon turned toward a 3 600 revolution, two-pole, rotating field type, and a very large number of possible constructions were considered. Finally one like that shown in Fig. 23 was worked out and built in 1899. This had the field windings completely embedded in a number of parallel slots, with supporting metal wedges at the tops of the grooves or slots. One machine of this type was built and tested. It operated in a satisfactory manner, except as regards windage and noise. The machine was not closed at the ends, like modern turbo-alternators, and thus any noise generated in the ma-

FIG. 21—ARMATURE FOR TURBO-GENERATOR OF TYPE SHOWN IN FIG. 20

chine could be readily transmitted to the outside. The noise was caused largely by the two flat sides of the rotor. It was so shrill and penetrating that it was very disagreeable to be around the machine, and was even painful to the ears after a short time. This construction was therefore abandoned temporarily, but after a few months it was taken up again and a new rotor was built which was entirely round, as shown In Fig. 24, but was otherwise very similar to that shown in Fig. 23. This new rotor, although noisy compared with modern machines, was so quiet, compared with the first construction, that it was immediately adopted as a standard construction. This is the now well-known parallel slot construction which has been used very extensively by the Westinghouse Company, although many very radical changes have been made in the constructive features of the rotor itself. This type of rotor was used originally only for

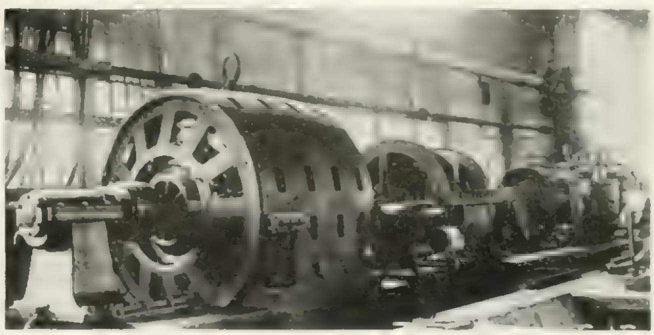


FIG. 22—1 000 KW OPEN TYPE TURBO-GENERATOR

the 400 kilowatt size at 60 cycles.

In the earlier machines of this type a number of very curious conditions developed. In the first machines the rotors were built of a number of thick discs or "cheeses" side by side, which were put on the shaft at high pressure. The two end discs were thicker

than the others in order to accommodate the grooves in which the rotor end windings lay. The discs were made of high grade forgings. After some of these machines had been in operation for a considerable period it was found that some of the discs in the field core were traveling axially, i.e., quite appreciable gaps

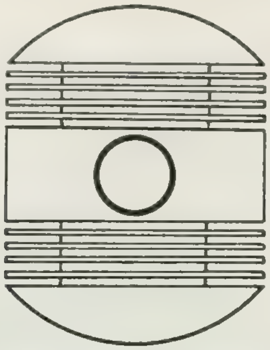


FIG. 23—EARLY TWO-POLE ROTATING FIELD

or spaces were showing between adjacent discs. In one instance they traveled to such an extent that the field windings were stretched longitudinally at the openings between the discs, until the conductors were actually attenuated to an extent visible to the eye. Obviously, the stretching force must have been enormous.

Eventually, the construction was changed on these two-pole rotors to a single disc of forged steel. Still later, steel castings were used quite extensively instead of forgings although, later still, the castings were abandoned in favor of forgings. There was much adverse opinion regarding the advisability of using castings for the 3 600 revolution machines, as some engineers held that they were more liable to contain flaws than would be the case with forgings. An interesting fact in connection with this is that, while a number of these early high speed machines "exploded," generally during runaways, yet in no instance was a cast steel field wrecked from this cause. This, however, does not constitute a proof of the superiority of cast steel, for it so happened that all the serious runaways were on machines with forged rotors. However, the record is a clear one as far as cast steel fields

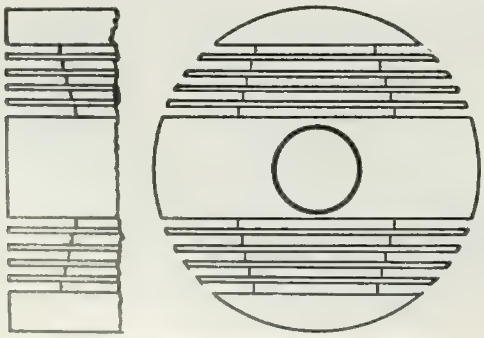


FIG. 24—ROUND TYPE TWO-POLE ROTOR

are concerned, for, of all the sizes and speeds of steel rotors which the Westinghouse Company has put out, not a single cast steel disc has burst. Present speed and output requirements have now carried the construction up to a point where special forged materials are the accepted practice.

Soon after the two-pole, 400 kilowatt rotating field machine was put on the market, a four-pole, 750 kilowatt, 1 800 revolution machine was built. The rotor of this machine had four salient poles bolted on. These poles were provided with overhanging pole tips, and the field winding consisted of four coils wound with strap-on-edge. In fact, this first construction was very similar to the present type of rotor fields now used for other than turbo work. This construction proved difficult and expensive, but was applied to a number of six-pole, 1 200 revolution machines. However, the parallel slot construction used in the two-pole machines was so satisfactory that it was soon adopted for the four and six-pole machines, as shown in Fig. 25. In the six-pole machine it was not possible to make the poles integral with the central core, on account of the inability to machine the parallel slots in the sides of the poles, or put in the windings. Therefore, separate poles were constructed, with parallel slots, and these

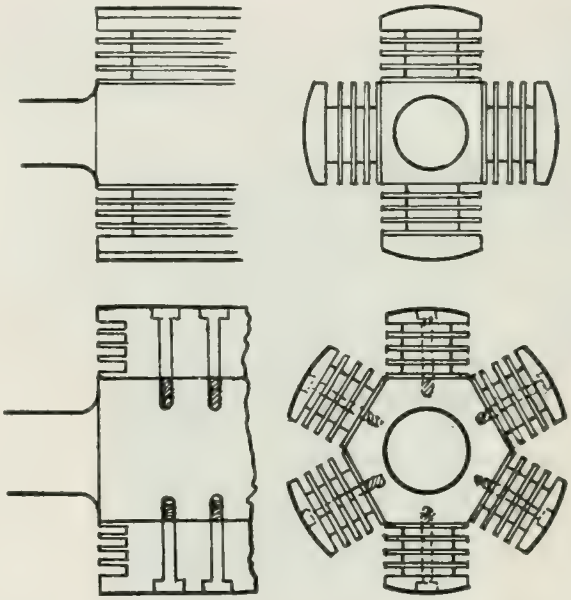


FIG. 25—PARALLEL SLOT FOUR-POLE AND SIX-POLE FIELD CONSTRUCTION

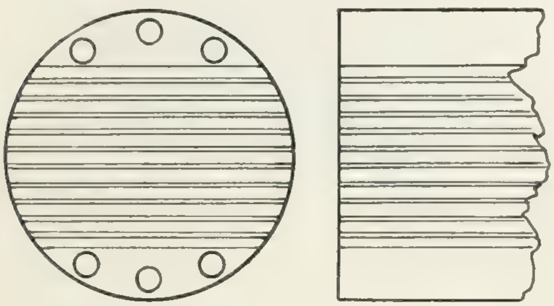
were first wound and then bolted into place on the central core which, in this case, was made integral with the shaft. The four-pole machine was constructed for 750 and 1 000 kilowatts capacity, and the six-pole construction was made for 1 500 to 3 000 kilowatts.

Meanwhile, there had grown up some demand for moderate capacity 25 cycle machines at 1 500 revolutons. These were constructed along exactly the same lines as the two-pole, 3 600 revolution machines above described.

In this early work one order for four 5 500 kw, four-pole, 1 000 revolution machines was taken. This was entirely beyond the constructions undertaken before by the Westinghouse Company. The parallel slot type of rotor was adopted. An attempt was made to get forgings in a single piece large enough for these rotors, but they were found to be glass hard and brittle, except at the outer surface. As very large steel castings were frowned upon, it was decided to make

these rotors of discs turned out of very thick steel plates, somewhat like the early 400 kw machines already described. Parallel slots were used as in the smaller four-pole machines. This construction proved to be feasible but was very expensive, and shortly after this large cast steel discs were used, two discs side by side being used to form one rotor. This construction was satisfactory, and was used for many years.

Shortly after turbo-generators came into general use, there was considerable complaint regarding the noise due to windage. All these machines were equipped with some form of ventilating device, which formed either part of the normal construction of the rotor or consisted of some special blowing device at the ends of the rotor. Both the high speed and the large quantity of cooling air required, tended to make a noise which was very objectionable. A series of



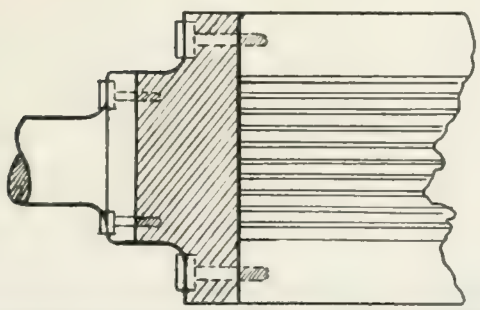


FIG. 26—TWO-POLE FIELD OF THE BOLTED ON CONSTRUCTION

experiments with covers over various parts of the machines, showed that, by completely enclosing the two ends of the machine and by enclosing the field frame except at the top and bottom, (in a horizontal machine) the windage noise could be so deadened as to be practically unobjectionable. However, the tests also showed that artificial ventilation was necessary under this condition. This very quickly led to the practice of enclosing and artificially cooling turbo-generators, which practice has been maintained to this day. The first Westinghouse enclosed machines were built about 1903.

The use of artificial cooling marked a great step in advance in turbo-generator work, for the results indicated that, by supplying a sufficient quantity of air and properly distributing it through the machine, very marked increase in capacity was possible, and a point was soon reached where the possible capacities were beyond the mechanical limitations of the construction. This led to radical modifications in the type of rotor, with a view to taking advantage of the increased capacity. Apparently all manufacturers did more or less development work along such lines. In the Westinghouse constructions, the use of a through shaft was found to be one of the serious limitations, and this led to types of rotors without any through shaft. In the two-pole machines, this was particularly important, and the problem was especially difficult with the parallel-slot construction, provided ample space was allowed for the field winding. The old through shaft two-pole construction lost considerable winding space, due to the shaft space, as shown before in Fig. 24. Attempts to construct such a machine with the shaft forming part of the core, resulted in still less efficient use of the possible winding space. It was obvious that if the whole possible winding space were taken up with slots, then the capacity of the field winding would be greatly increased. In consequence, a rotor construction, such as shown in Fig. 26, was designed and constructed. In this, bronze end supports or "heads" were bolted to each end of the field core, and the shaft proper was attached to these bronze heads. Bronze, or a similar non-magnetic material, was necessary to prevent magnetic short-circuiting of the field flux. This design was constructed and tested on a 1 000 k.v.a., 3 600 revolution machine, and then was built successively for 1 500, 2 000, 3 000. 4 000 and 5 000 k.v.a. machines, all at 3 600 r.p.m. The same construction was also applied to two-pole machines of 25 cycles, up to 12 000 k.v.a. capacities. This construction of rotor has given an extremely good account of itself. However, it proved to be expensive on small capacity machines, as the bronze heads formed an undue proportion of the cost of material. For higher capacities of 3 600 r.p.m. machines, increase in capacity is obtained largely by increasing the length of the rotor core, and thus the bronze heads form a relatively lower percentage, and the construction becomes more reasonable in cost.

From the preceding, it may be seen that only two types of turbo-generators have been used very extensively, namely, the parallel-slot type and the radial slot. Each of these types has some very pronounced advantages. The principal advantage of the parallel-slot type is in the arrangement and support of the field coils. Each coil can be wound directly in place, with the conductor under tension, and the finished winding is completely encased, and is thoroughly protected against dirt, movement of the conductors, etc. Against this, the radial slot machine allows more room for copper, and is magnetically more economical in material. However, the field windings are more difficult to apply and must be supported at the ends by auxiliary means, such as separate external steel rings.

The enormous increase in output of turbo-generators, within very recent years, has made the electric

and magnetic proportions of the rotors a feature of first importance in the design, so that the radial slot type for two-pole machines has become the standard construction, almost universally. This will be referred to again under the four-pole construction.

While the two-pole parallel slot construction was being developed for larger capacities, the four-pole construction for 60 cycle machines has been

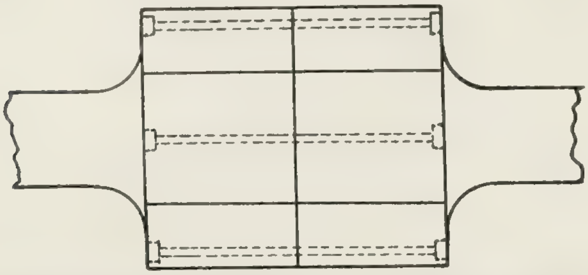


FIG. 27—FIELD CONSTRUCTION WITH TWO HALVES HELD TOGETHER BY HEAVY BOLTS

pushed up to capacities of about 12 000 k.v.a. with the parallel slot, cast steel rotors. In order to do away with the through shaft construction, the rotor was made of two castings or discs, each of which was cast solid with the shaft, as shown in Fig. 27. The two discs, after machining, were bolted together by a number of very heavy bolts located near the pole tips and, in some cases, shrink links were placed in the pole face, connecting the two halves together. The parallel grooves were then machined in the steel core, just as in the through-shaft type. In this four-pole construction, the problem of armature ventilation was comparatively simple. Air-gap ventilation (that is, all air through the armature core supplied from air-gap) was easily accomplished, due to the open spaces between the poles, which could admit an ample air supply. However, the same construction tended toward high windage losses due to air "churning."

This problem of ventilation has had much to do with the evolution of turbo-generator design.* In the two-pole, parallel slot machine for 3 600 r.p.m., in which the diameter of the rotor is relatively small, the amount of air which can be forced into the air-gap from each end is rather limited. Assuming, for example, a rotor diameter of 24 inches, which is almost as large as we can go for a 3 600 r.p.m. machine, then, with an air-gap (iron to iron) of ¾-inch, which is also a fairly large gap, the total cross-section of the air inlet at the air-gap at both ends of the rotor will be 112 sq. in. With the very high air velocity of 10 000 ft. per minute, this means a total air supply of less than 8 000 cu. ft. per minute. This may be sufficient for a moderate capacity turbo-generator, but for machines of high capacities, such as 3 000 to 5 000 k.v.a., this is not nearly enough cooling air. Obviously, either much larger inlets through the air-gap are required, or some additional method of cooling is necessary. Larger air-gaps usually mean either more expensive machines, or reduced output with a given machine, due to lower flux densities. Therefore, the tendency, in machines of the very high capacities, and very high speeds, has been toward a combination of air-gap with other methods of ventilation. In the 25 cycle, two-pole machine with a maximum speed of 1 500 r.p.m., rotors of larger diameter are possible and, as a rule, much larger air-gaps are practicable than in 60 cycle machines. In consequence, air-gap ventilation comes nearer being practicable but, in the larger capacities, even this is insufficient and auxiliary methods have been necessary in some cases.

This need for auxiliary methods of ventilation led to the axial method of ventilating armature cores in distinction from the radial method, in which the air was carried out through numerous radial air ducts or passages. In the axial method, a large number of ventilating holes are arranged in the armature core parallel to the axis of the machine. These form ventilating paths in parallel with the air-gap path. With the small diameter long cores necessary for 3 600 r.p.m., high capacity machines, the development of this method of ventilation was contemporaneous with the development of the higher capacities. The same has proven to be the case for the later types of Westinghouse four-pole, 60 cycle, 1 800 r.p.m. machines, which departed very considerably in rotor construction from the four-pole cast steel type already described.

As the capacities of the 3 600 r.p.m., 60 cycle machines were gradually pushed up, a corresponding development occurred in the 1 800 r.p.m. machines. At 10 000 to 12 000 k.v.a., the four-pole cast steel construction was apparently approaching its limits. For larger sizes, therefore, a different construction was adopted which allowed more suitable material to be obtained. For the largest diameters and highest

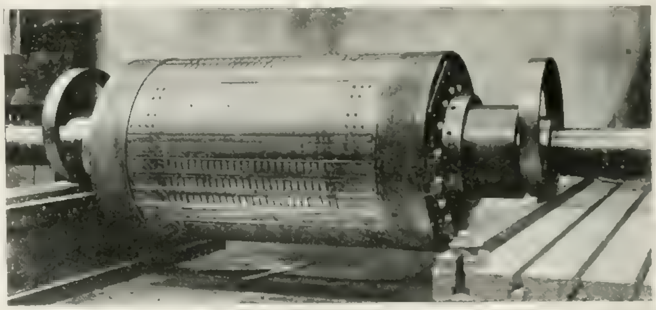


FIG. 28—MODERN ROTATING FIELD ON BALANCING WAYS

speeds, a plate construction was adopted by the Westinghouse Company, in which the end discs and the shaft ends were forged as units, and the intermediate discs were made of rolled plate material, the whole construction being bolted together permanently to form a solid core. This core was then slotted with radial slots, and the usual radial slot type of field winding is used. A similar construction was adopted on the

*A more complete exposition of the subject of "Turbo-Alternator Ventilation," etc., is contained in a paper by the author, read before American Institute of Electrical Engineers, January, 1913.

larger 25 cycle machines. For intermediate capacities, both 60 and 25 cycles, solid discs are used in some cases instead of the plate construction. This brings the larger turbo development up to the present date.

In the comparatively small 60 cycle turbo-generators, where the parallel slot construction with the bronze driving heads was relatively expensive, as already described, the later development has been towards core and shaft forged in one piece, and with radial slots, and eventually this construction may be carried up to the largest practicable size of 3 600 r.p.m. machines. It is difficult to predict the limit in capacity which may be reached eventually in 3 600 r.p.m. generators but 6 250 k.v.a. appears to be practicable.

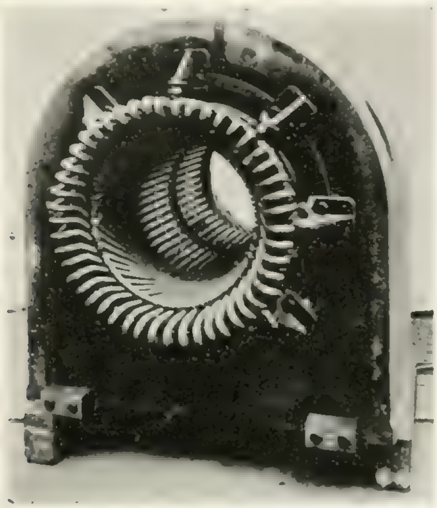


FIG. 29—STATOR OF 625 K.V.A., 2 300 VOLT, 3 600 R.P.M. TURBO-GENERATOR

With axial ventilation and central duct. Supporting ring both inside and outside the end windings. Typical method of bracing smaller machines.

Some special radial slot machines had been developed for the New Haven Railroad about 1907. As these machines were designed to deliver 25 cycle single-phase current, and as the pulsating armature reaction of such machines would be relatively high, the rotors were designed with laminated cores, with a view to lessening core losses. The rotors were made of single disc lamminations shrunk on the shaft The discs were provided with radial slots. The construction was very similar to the later radial slot rotors, except that the rotor end windings were also embedded in slots, and supported by wedges embedded in the periphery of the core, whereas, in the later radial slot rotors, the end windings are supported by external rings. These early radial slot rotors showed very considerable overheating in single-phase operation, and it was found necessary to apply a very complete cage damper embedded in the periphery of the rotor. Later experience showed that the solid core parallel slot rotor with an equal damper applied to its surface was just as effective, and many of the later single-phase machines were built in this manner. However, some recent 11 250 k.v.a. single-phase generators are being built of the plate construction already described.

REGULATION AND SHORT-CIRCUIT CURRENTS OF TURBO-ALTERNATORS

Like the ordinary synchronous generator, the modern turbo-alternator is designed with a comparatively high inherent regulation. In fact, in order to avoid excesive short-circuit currents, the inherent regulation must be made comparatively poor by making the armature self-induction as high as practicable. Even under the best condition, such machines are liable to give 12 to 15 times rated current during the first current rush. Furthermore, the solid plates or discs, of which most turbo-rotors are now made, tend to prolong the period of maximum short-circuit current. The consequence of these conditions is a tremendous racking force acting on the end windings during a short-circuit current rush, which tends to distort the winding badly unless it is very strongly braced. The Westinghouse Company encountered such a difficulty on some of their earliest turbo- alternators and there has been a practically continuous development along the lines of more substantial bracing which has kept pace with the increased requirements of the higher speeds and the higher capacities. The bracing used on the modern machines is designed to resist distortion of the end windings, under dead short-circuit, without reactances interposed, and each new size as it is developed is given such a short-circuit test. A 20 000 k.v.a. 60 cycle, 1 800 r.p.m. high voltage alternator was recently subjected to such short-circuit tests at full voltage without injury.

The preceding gives a brief history of the development of the turbo-generator, insofar as carried out by the Westinghouse Company. The General Electric Company went through a corresponding course of development, in general, although not in the specific constructions described, and a number of interesting types or constructions have been brought out. The gradual increase in speed has undoubtedly had much to do with the evolution of their various types, just as in the case of the Westinghouse evolution. One of the most radical steps which the General Electric Company has made in the past few years is in the change from the vertical to the hori-

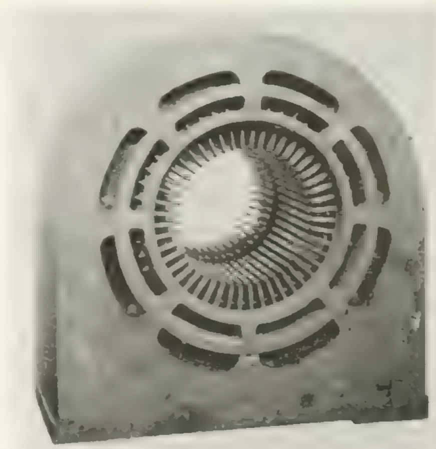


FIG. 30—SAME MACHINE AS SHOWN IN FIG. 29 BEFORE WINDING

zontal type of machines. Presumably the very high speeds which later came into use have had much to do with this change. In the earlier turbo-generator practice, the speeds of the General Electric Company's machines were relatively lower than the Westinghouse, presumably on account of the type of steam turbine used. Many of the early rotor constructions were of the salient pole type for four poles and higher. Gradually these were superseded by constructions leading up to a radial slot type in which the slots were formed by teeth inserted in dovetail grooves in the rim of the spider. This type was very similar in appearance to the later types, except that the slots had overhanging tooth tips, thus giving a partially closed slot construction. More recently, with greatly increased speeds, this construction has been superseded by solid forged cores with shaft forged on, and with radial grooves milled in the surface for the field

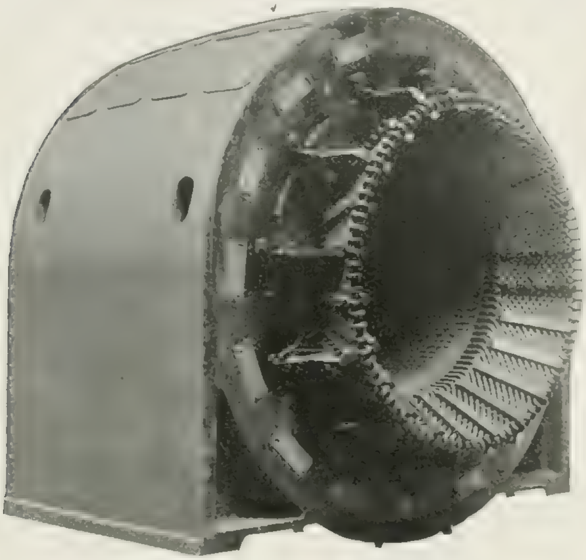


FIG. 31—STATOR OF LARGE MODERN TURBO-ALTERNATOR
Showing end winding and method of bracing large machines to withstand short circuits.

winding. These latter rotors are used largely in the horizontal type high speed machines.

In the Allis-Chalmers construction, in the larger machines having four or more poles, the earlier construction of the rotor consisted of forged discs with through shafts. These discs had radial slots for the windings very similar to the present construction of all manufacturers. The smaller machines generally had cores forged in a single piece with the shaft, and with radial windings. As regards methods of ventilation, both the General Electric and Allis-Chalmers Companies went through a course of development leading up to their present practices.

As regards parallel operation, turbo-generators have been particularly free from this old time difficulty, due largely to the uniform rotative effort of the steam turbine, and partly to the high flywheel capacity of the turbo-generator and turbine rotors, which tends to limit any speed oscillations, due to the governors, to a relatively low period, such as would not tend to accentuate the hunting action in the generators themselves. Moreover, in those rotors which have been built with solid cores or of thick plates, the solid material tends to act as a damper circuit. As a consequence, hunting in turbo-generators, or difficulties in parallel running, have been extremely rare.

INDUCTION TURBO-GENERATORS

This type of turbo-generator has been proposed commercially a number of times during the past ten years, and a few installations have been built. The first of any importance, consisting of a 1 250 kilowatt generator of 30 cycles, 1 800 r.p.m., two poles, was installed in the plant of the Baltimore Copper Smelting & Rolling Company. This generator was a true polyphase induction motor, direct connected to a steam turbine. The construction of the generator was exactly the same as would have been used at that time in a two-pole, 1 800 r.p.m. induction motor of the same capacity. The entire load of this machine consisted of a 1 200 kilowatt rotary converter connected directly to the terminals of the generator. The generator and converter were brought up to speed separately and the rotary converter, with its field excited, was connected directly to the generator and furnished the excitation for the generator. There was no other synchronous apparatus in circuit except the converter.

Several years ago, a number of much larger induction generators were built by the General Electric Company for the Interborough Rapid Transit Company of New York City. These machines are of 6 000 k.v.a. nominal capacity and operate in parallel with the 11 000 volt, three-phase, engine-type generators previously installed in the same power house. The engine-type generators furnish the excitation for the induction generators. The entire load of this station is represented by rotary converters. There have been no prominent instances of the use of induction generators for other than steam turbine drive. Apparently this type of generator has no very wide field.

CONCLUSION

This history is admittedly far from complete, in that it has not mentioned the work of some of the earlier, and also some of the later manufacturing companies. The field is far too large to permit everything to be covered. Moreover, no attempt has been made to describe European constructions and developments in alternating-current generators. It may be stated, however, that in some very important features, European engineers antedated the Americans, while in other equally important constructions American designers were first in the field. As a rule, the representatives of the electrical manufacturing companies have been so wide awake and ready to adopt new principles when they contained any promise, that it is sometimes very difficult to give any company or individual proper and deserved credit for being first in any given development. Furthermore, no attempt has been made to give credit to the various engineers who have been closely identified with alternator development, for it would be impossible to do justice, or give deserved credit to all of them.

The Protection of Transmission Circuits by Relays

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THE growth of the electrical industry with its accompanying demand for greater insurance for continuity of service has resulted in numerous developments in the way of protective apparatus during the last few years. A number of different ideas have been presented for obtaining selective action from different types of relays, and along this line there is little left to be said that would be new to the average electrical engineer. But as the means for carrying out these ideas have not been standardized, there are a number of types of relays, with widely different characteristics, used when the object to be accomplished is the same. It is my object here to differentiate between the characteristics of some of the most common types and to give some results obtained both in tests and in practical operation.

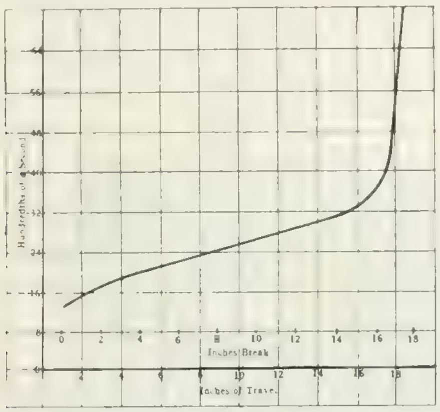


FIG. 1—CHARACTERISTIC CURVE OF A STANDARD CIRCUIT BREAKER

It has been contended by some that extreme accuracy in the operation of relays is unnecessary and that to obtain operations within fractions of seconds would entail an unwarranted expense. The writer, however, considers that accuracy, in the operation of relays, particularly in their time setting, is of paramount importance, since the time of a few cycles during a short-circuit may mean the dropping of synchronous load; and it can be seen that a few cycles added to the setting of each of a number of relays operating in series may amount to a second or more on the relays near the source of power. Wherever selective operation is to be accomplished, some type of time limit relay must be used. In some cases the desired results can be obtained by the use of definite time limit relays but the inverse time limit relay is better adapted to the conditions generally existing. The last named type is sometimes designed to operate in a definite time at high values of current. This form is coming more and more into use and is probably giving better results than any of the others.

With respect to the method of obtaining the time lag on these relays, they are divided into two distinct classes, namely, those that obtain the time lag by mechanical means, such as gears or bellows and those that employ magnetic damping means. The time of the first class, being dependent upon friction, can never be accurate and therefore relays of this class, in order to operate selectively in series, must be set at a greater time difference than if their time characteristics were accurate. The time of the second class is independent of friction and therefore has an accurate time characteristic. The time difference in the setting of such relays when operating in series to give selective action is dependent only upon the time required for the automatic apparatus connected with them to perform their functions.

In order to obtain satisfactory results from the operation of relays in practice it is necessary to know not only the operating characteristics of the relays, but also those of all the automatic apparatus connected with them. With the object of obtaining this information a number of tests were made as follows:—

First, the operating characteristics of two oil circuit breakers of standard make were determined to be as shown in Figs. 1 and 2. These characteristics are quite different, but it will be noted that, in each case, contact is broken about 0.13 of a second after tripping current is applied to the switch and, as one of the switches opens the contacts only eight inches, which operation requires 0.28 of a second, this time may be taken as the maximum time required for a standard switch to interrupt a short-circuit, although the circuit may be broken at any time between 0.13 and 0.28 of a second, depending upon the capacity being interrupted.

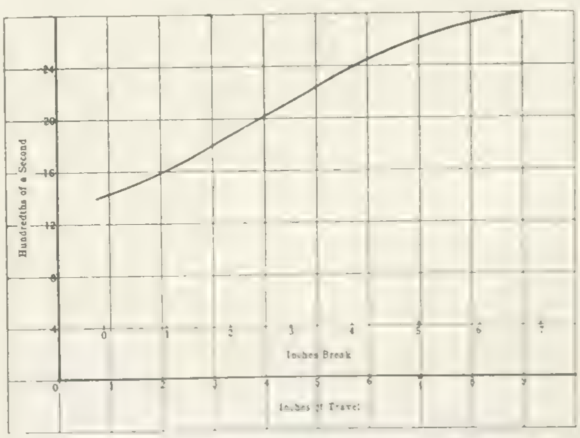


FIG. 2—OPERATING CHARACTERISTICS OF A SECOND STANDARD CIRCUIT BREAKER WITH THE SAME TIME OF BREAK REQUIRED AS IN FIG. 1

Then four oil circuit breakers, having characteristics similar to that shown in Fig. 2, each being con-

trolled by its respective relay, were connected as shown in Fig. 3; so that the opening of any oil switch would interrupt the circuit of the actuating coils of all the relays, just as would be the case when an equal number of switches were controlling four circuits operating in series in a distributing system.

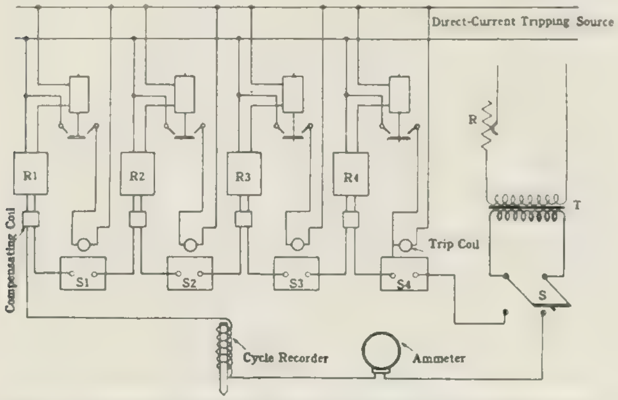


FIG. 3—DIAGRAM SHOWING FOUR OIL CIRCUIT BREAKERS CONTROLLED BY INDIVIDUAL RELAYS

The induction relays, R_1, R_2, R_3 and R_4 close the direct-current circuit through a magnet coil, which in turn closes the trip coil circuit.

Also in the circuit of the switches was an ammeter for measuring the current in the circuit and a cycle recorder for measuring in fiftieths of a second the time during which the current continued to flow. To demonstrate the selective operation of the relays all of them were adjusted to close their contacts with ten amperes in their actuating coils. Then with the resistance *R* adjusted to give one hundred amperes in the circuit of the relays, the switch *S* could be opened and closed any number of times without any of the automatic switches except *S-1* opening; and if switch *S-1* was made inoperative *S-2* would operate every time without disturbing *S-3* and *S-4*; likewise with *S-1* and *S-2* blocked only *S-3* would operate and with *S-1*, *S-4* and *S-3* blocked *S-4* would open the circuit every time in approximately 1.5 seconds. The above is shown diagrammatically in Fig. 4.

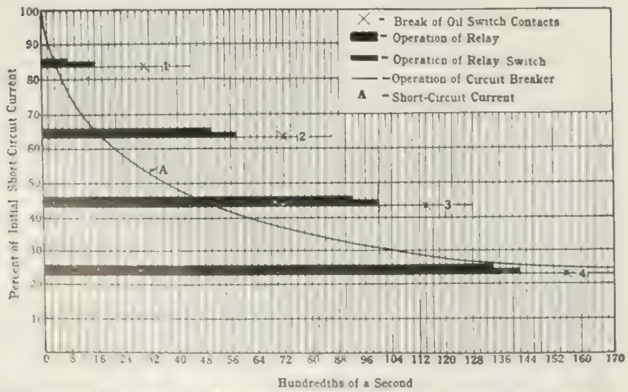


FIG. 4—DIAGRAMMATIC REPRESENTATION OF SEQUENCE OF OPERATIONS WITH CONNECTIONS AS IN FIG. 3, AND CURRENT CURVE IN PERCENT OF SHORT-CIRCUIT CURRENT

In order to accomplish the above results within such narrow limits it was necessary that the relays should be extremely accurate, since a variation in time of even 0.1 of a second might give the wrong sequence of operation of the switches. Therefore an induction type overload relay which employs the magnetic damping principle was used throughout, as it was found to be accurate through any number of tests to within 0.04 of a second. This relay is shown with cover removed, in Fig. 5. In order to obtain the necessary time at such high values of current each relay was provided with a compensating coil which not only made it possible to operate the switches selectively at very high current values, but also insured the accuracy of the relay under excessive flow of current by limiting the current in the actuating coils of the relays to a value near that at which the relays were set. This feature does away with the high rate of speed of the moving element of the relays which usually results in over-shooting and the consequent tripping of the oil switch after the current in the actuating coil has been reduced within safe limits. In practice this feature is of extreme importance, as with some types of relays the circuits are often cut out after the trouble is clear.

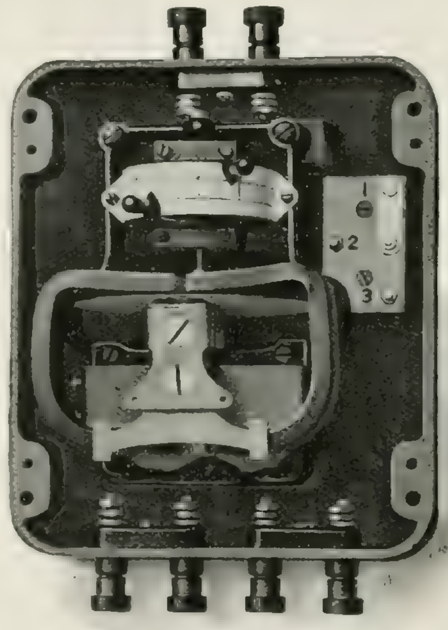


FIG. 5—INDUCTION TYPE OVERLOAD RELAY WITH COVER REMOVED

In Fig. 4, *A* shows the relative values of current interrupted by the different switches. Curve *A* varies for different generators, but the values here shown are a fair average. It will be noted that switch *S-1*, the one farthest from the source of energy, is called upon to interrupt approximately 55 percent of the maximum short-circuit current, while switch *S-4* has only to interrupt about 25 percent of the maximum or one-half of that interrupted by switch *S-1*. This shows that, if the relays operate selectively, there is a possibility of the strain on the switch at the end of the line being greater than that on the one nearer the generator. Of course there is an argument that the current interrupted by switch *S-2* will be less than that interrupted by *S-4*, due to the greater impedance in the circuit, but this decrease in current due to added impedance will seldom if ever equal the increase of current at the time switch *S-1*

opens, due to the greater degree of magnetization of the system. Further if switch *S-1* opens the circuit the voltage will rise instantly to, say, 55 percent of normal, tending to maintain the arc, while if switch *S-4* opens the circuit, the voltage will follow the arc to 25 percent of normal and then slowly to normal.

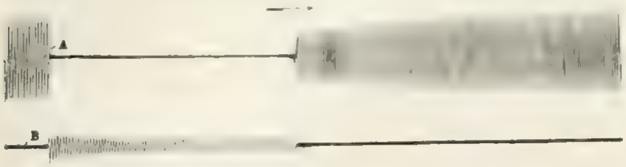


FIG. 6—OSCILLOGRAMS SHOWING BEHAVIOR OF VOLTAGE A AND CURRENT B DURING SHORT-CIRCUIT AND DIRECTLY AFTERWARDS

These percentages are assumed for comparison and may vary under different conditions, as they will be affected by both the characteristics of the circuit and the apparatus connected thereto.

For an illustration of the building-up of the voltage on a system that has been demagnetized by the effects of a short-circuit refer to Fig. 6, which shows the voltage *A* and current *B* on a 60 cycle generator which was short-circuited for about one and one-half seconds. It will be noted that when the short-circuit was interrupted the voltage immediately rose to about 50 percent normal and did not reach its original value until approximately two seconds after the short-circuit was interrupted. This test was made on a generator without load, which is the most favorable condition for the voltage to restore itself after a short-circuit.

In some cases the satisfactory operation of low grade switches at the end of the line has been due to the fact that, owing to defective operation of relays, other switches nearer the generators have also opened on severe short-circuits, this reducing the strain on the switch at the end of the line.

With the foregoing information it is possible to relay almost any distributing system so that in case of failure of any piece of apparatus only the switches directly controlling that piece of apparatus will open, provided certain characteristics of that particular system are taken into account. A simple illustration of the setting of relays to accomplish the above result in practice is as follows:—

Referring to Fig. 7,—*1*, *2* and *3* are generators feeding bus *A*; *4*, *5* and *6* are cables connecting bus *A* with a sub-station bus *B*; and *7* and *8* are sub-station machines. As a general rule all relays on a distributing system should be set to trip at a minimum of 300 percent normal full-load current except receiving apparatus such as rotary converters, motors and transformers which should be set for a minimum of 400 percent full-load current. Unless otherwise stated these values will be assumed in the present discussion.

Assume that machines *1*, *2* and *3* have a rated capacity of 100 amperes each and that the regulation of the system at 300 amperes at bus *B* is 15 percent; then in case of short-circuit at bus *B*, or in machines *7* and *8*, the maximum current during the first cycle would be approximately 2 280 amperes which would decrease to about 900 amperes in approximately one second as shown by Fig. 6. Then, considering that one of the cables, *4*, *5* or *6* is out of service, each of the remaining cables would have a maximum current of 1 140 amperes and, if relays at *9*, *10* and *11* are set to give, at this value of current, a time of 0.5 of a second, any breakdown beyond relays *12* and *13*, which are set to operate in 0.08 of a second at 1 140 amperes, would be cut out by switch at *12* or *13* without either of the switches *10* or *11* opening. When all three cables are in service the current in each cable would be less, which would result in a greater margin for selection. Relays at *14*, *15* and *16* should be set to operate in 0.92 of a second with 1 140 amperes flowing in each cable so that they could never operate sooner than the corresponding relays at *9*, *10* and *11*, provided the current is feeding through the cable to bus *B*, but, if one of the cables should short-circuit, say at *X*, then the current flowing through the relay at *14* may exceed by a considerable amount the maximum current—1 140 amperes—at which it has to select over relay at *9*. Under these conditions the relay at *14* may operate in approximately 0.1 of a second and the current feeding back through *9* would be twice that flowing in *10* or *11*, so that cable *4* would be cleared in a small fraction of a second while all of the other apparatus would remain to operate only when trouble occurs in the machine which it controls. This can be done best by using three straight overload relays for each machine, each relay to be connected to two current transformers connected one at either end of one phase of a machine, so that no current flows in the actuating coil of the relay when the machine is operating normally, but as soon as there is trouble in the machine current will pass through one transformer without passing through the other and the relay will operate instantly.

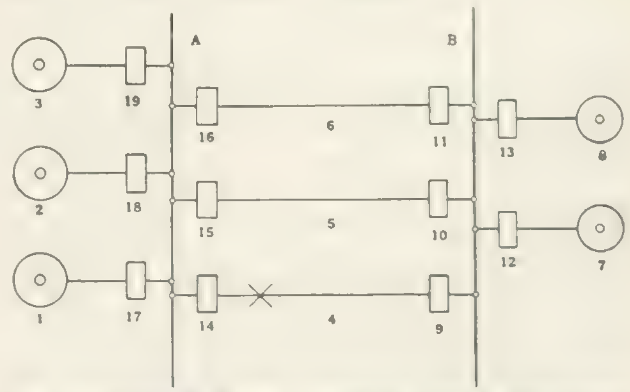


FIG. 7—SINGLE LINE DIAGRAM SHOWING TYPICAL CONNECTIONS FOR A GENERATING STATION AND ONE SUB-STATION

It must be remembered that when straight overload relays are used, it is necessary to have three pieces of apparatus in parallel in order to insure the service beyond the said apparatus. For example there must be at least three cables from a generating station to a sub-station in order to insure the service at the

sub-station when one of the cables fails: During the time the Consolidated Gas Electric Light & Power Company of Baltimore has used the principle outlined in reference to Fig. 7 for setting relays, there have been a number of cable breakdowns, and in no case has any apparatus other than the damaged cable been disconnected from the system and, owing to the short time necessary to give selective action with the relays in use, the damage to cables has apparently been

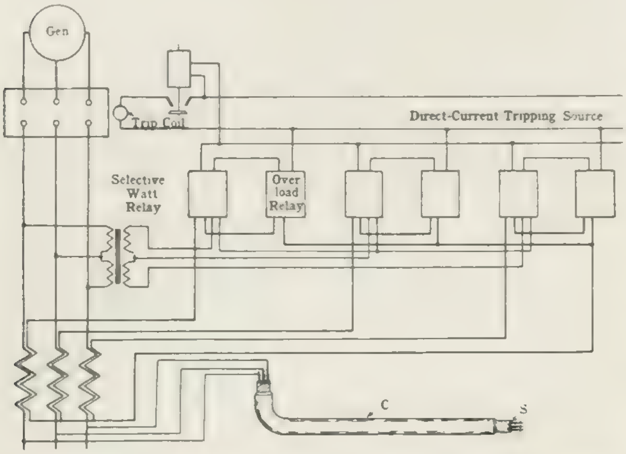


FIG. 8—RELAY CONNECTIONS WITH SELECTIVE WATT ELEMENT INSURING OPERATION OF RELAYS FOR ONE DIRECTION OF CURRENT ONLY

no greater than previously when in each case a number of oil switches would open simultaneously.

The above is to illustrate the principle of setting straight overload relays with inverse time; however, much better results can be obtained by using, in connection with the overload relays, a selective watt element which makes the relay operative on energy flowing in only one direction, which not only insures against the opening of switches when current is flowing in a direction in which it is never advisable to interrupt it but also reduces the time necessary for the selective operation of a number of relays in series by one-half. Since these selective elements depend upon voltage for their operation and as the voltage is a very uncertain factor in times of trouble, the following tests will serve to show the possibilities and limitations of this device:—

Connections were made as shown in Fig. 8, the selective watt relays being connected to open the tripping circuit of the overload relays when current flowed from the generator to the cable *C* and the overload relays were set to trip at about full load of the generator. The cable was of such length that the ohmic drop in each conductor was 1.14 percent of the normal voltage of the generator when current equaling the sustained short-circuit current of the generator flowed in the conductors. With the above conditions, an arc was started at the end of the cable at *S* at which point the conductors were the same distance apart as in the cable. The generator switch did not trip on a number of tests but when the potential circuits of the selective relays were reversed giving the conditon of reverse energy the generator switch would trip on each occasion that an arc was started at *S*. These results showed that the selective watt relays can be depended upon to make the overload relays inoperative when energy flows in one direction in a circuit, while they do not interfere with their operation while energy flows in the reverse direction, provided the voltage of the circuit is not less than two percent of normal at the point from which the selective relays receive their potential. But when the cable was only a few feet long it was found that the voltage across the arc at *S* was not sufficient to give the required potential for the relays, and their operation was the same regardless of the direction of energy flow in the conductors. In all of the above tests the current in the relay circuits was approximately ten amperes. The above would seem to indicate that, while the selective relays can be used to good advantage where the conductors are of sufficient distance apart to give the required voltage across an arc to operate the selective relays, as a general rule they would not be applicable to cable protection.

To show the advantages gained by the use of selective watt relays wherever conditions will insure the necessary voltage for their proper action, reference is made to Fig. 9, which illustrates a ring system of distribution. The ring is made up of three sub-stations and a generating station connected in series by cables forming a ring. At each end of each cable there is a switch, each switch being controlled by an overload selective watt relay with compensating coil to give selective action as shown in Fig. 10. These relays will operate only when energy flows through the switches in the direction indicated by the arrows. The

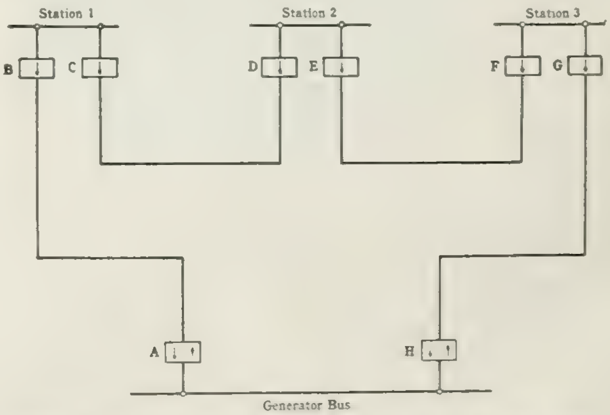


FIG. 9—A RING SYSTEM OF POWER DISTRIBUTION WITH RELAY PROTECTION

total generating capacity feeding through the impedance of the entire ring was calculated and then, as explained in reference to Fig. 7, the maximum current that could flow through the relays at *G* and *B* in the direction indicated by the arrow was determined to be 3 600 amperes. Therefore, at this value of current, all of the relays operative when current flows around the ring in one direction were made selective by 1/3 of a second as shown in Fig. 10. Then the regulation

of the system feeding either way through the ring to sub-station *2* with maximum capacity in generators was such as to give a maximum current feeding either way to sub-station *2* of 4 500 amperes; therefore at this current, relays operative on energy flowing either way through the ring relays at *H* and *F* or *A* and *C* should be selective by at least 1/3 of a second. In order to make the relays selective at lower values of current, each relay is set to trip at 100 amperes less than

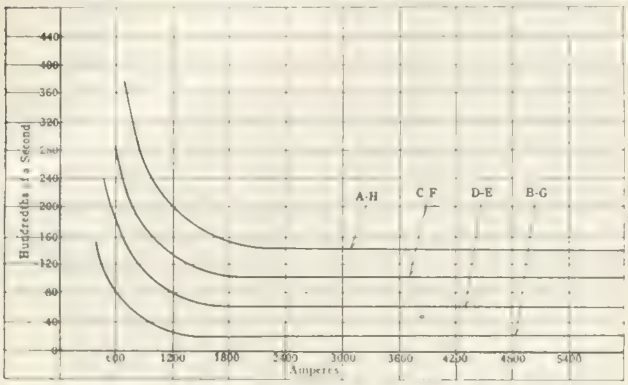


FIG. 10—CURVES SHOWING SELECTIVE ACTION OF RELAYS OF FIG. 9

the one next succeeding feeding either way around the ring.

From the above it can be seen that in case of short-circuits on either of the feeders leaving the generating station this feeder would be cut out at both ends while all the sub-stations would be fed around the ring in the other direction. And if a short-circuit should occur in one of the tie cables, say between sub-stations *2* and *3*, switches at *E* and *F* would open, leaving sub-station *3* feeding from one direction and sub-stations *1* and *2* feeding from the other. Any trouble that might occur in one of the sub-stations would be cleared by the opening of the switches at the remote ends of the cables supplying that station without interrupting service to either of the other stations.

While the above is in reference to a system of three sub-stations, the principle on which the relays are set will apply with equal accuracy to a system of any number of stations such as that in Fig. 11,

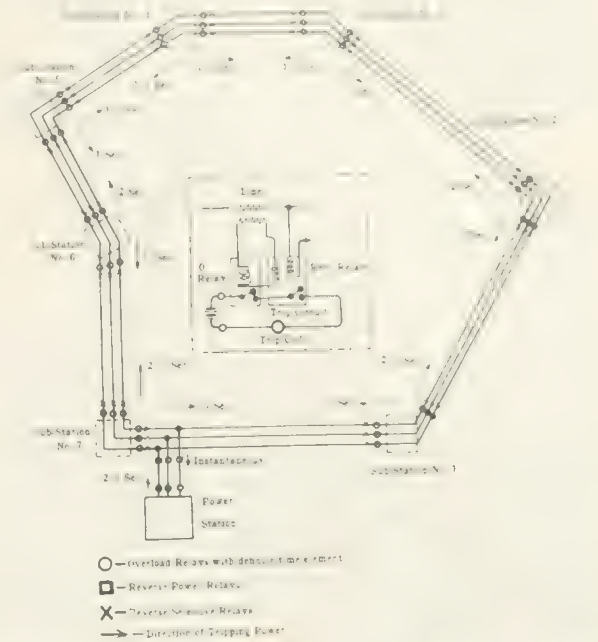


FIG. 11—TYPICAL RING SYSTEM INVOLVING SEVEN SUB-STATIONS, INDICATING PROTECTIVE APPARATUS USED, ITS LOCATION AND SELECTIVE ACTION

The diagram in the middle shows the connections of the selective watt type of relay.

which involves seven sub-stations, and in fact the fundamental idea of allowing the feeder switches at sub-stations to open automatically only in response to energy flowing away from the sub-station bus-bars is applicable to systems in general, whether the feeders are working in series or in parallel.

Shop Testing of Electrical Apparatus—XVI

SINGLE-PHASE TRANSFORMERS

TO OBTAIN a complete knowledge of the performance of a transformer, the following tests are required:—

1—Tests for determining continuity of service; temperature and insulation.
2—Tests for determining the quality of the service; resistances; impedance and regulation.
3—Tests for determining the economy of operation; iron loss; copper loss; exciting current and efficiency.
4—Tests to determine correctness of internal connections; ratio and polarity.

For convenience in making the tests, they are usually not run in the order given above. Some should be made when the transformer is cold, others, when it is at its full-load operating temperature. In general, a complete test is run on only one transformer of a lot, and the others are only checked sufficiently to determine their conformity to the sample.

Oil insulated transformers should always be tested under oil, if the voltage used in the test approaches normal potential. The insulation on low voltage transformers will ordinarily stand up to normal test potential without the presence of oil, but taking unnecessary risks is inadvisable. While some tests are made customarily by transformer manufacturers before the transformer is placed in its case, as a matter of convenience, after the transformer has once been completely assembled all tests should be

made with the transformer as nearly as possible in normal operating condition.

RATIO

The ratio of a transformer is the numerical ratio of the primary voltage to the secondary voltage, and should be the same as the ratio of the number of primary turns to the number of secondary turns.

When testing a transformer for ratio, the first step is to apply a low voltage to the total high tension

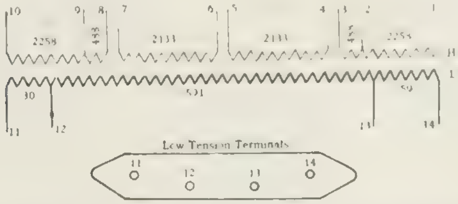


FIG. 1—DEVELOPMENT OF WINDING FOR A SINGLE-PHASE 33 000 TO 2 300 VOLT, 60 CYCLE TRANSFORMER

winding and check the order and position of terminals as shown in its wiring diagram. Usually about one hundred volts is sufficient. After having checked the numbering and location of the terminals on the terminal board, the complete ratio is usually best determined by impressing one volt per turn on the total high tension winding, as in this way the number of turns is then read directly in volts. If one volt per turn would not give a readable deflection on the most accurate part of the voltmeter scale, the applied voltage may be changed to some even fraction or multiple thereof, as the case may demand, providing the voltage does not exceed the rated voltage of the transformer.

When checking tap ratios by the ordinary method on small capacity, high voltage, core-type transformers, it is almost impossible to obtain accurate ratios of the taps by reading the voltage over the taps, since the current taken by the voltmeters is an appreciable load for that part of the winding, in series with the rest of the winding, causing a voltage drop which causes an apparent error in the ratio of the taps. To obtain the ratio of the taps on such a transformer, it is necessary to apply at least one volt per turn to the high tension windings and read the voltage on the low tension. Then, by cutting out the taps on the high tension one after another, and applying one volt per turn to the remainder of the high tension winding, one volt per turn should be read in each case on the low tension winding.

The ordinary method of procedure may best be understood from the following examples:—

A diagram of a single-phase 33 000 volt high tension—2 300 volt low tension, 60 cycle, core-type transformer having 9 758 turns in the total high tension windings and 680 turns in the total low tension windings, is shown in Fig. 1, giving the number of turns in the respective windings and the location of the taps. The various taps should be stepped out and checked for position as indicated above. The low voltage applied may be of any convenient value, such as 200 to 300 volts. The ratio test proper may then be taken up. Not less than one-half volt per turn should be impressed on the high tension winding of a transformer of this size. Since there are 9 758 turns on the high tension winding, this will necessitate 4 879 volts on the total high tension and there will be 340 volts on the low tension if the ratio is correct. The taps on the high tension side are then checked by cutting out the part of the winding from *2* to *3*, this being done by means of a connector for connecting terminals *2* to *4*. Apply one-half volt per turn, *i. e.*, 4 635 volts to the remainder of the high tension winding and read the low tension voltage; this should still be 340 volts. In a like manner the taps *8* and *9* are tested.

The low tension taps should be checked by impressing one volt per turn on the low tension windings and reading the voltages:—

11 — 12 = 30 volts = 30 turns.
13 — 14 = 59 volts = 59 turns.

If the ratio test is made with the transformer out of the tank, care should be taken that a core type transformer is not placed close to a cable carrying a large current of the same frequency as that being used for the ratio test, as there is a possibility that the stray field from the cable will pass through one side of the core, which will tend to cause an apparent error in the ratio.

As a second example, consider a single-phase, 2 200 volt to 220-110 volt, 60 cycle, manhole transformer having 200 turns on the high tension windings and 20 turns in the low tension windings. Fig. 2 gives the development of the winding, number of turns and location of taps in the respective windings, together with terminal board showing the location

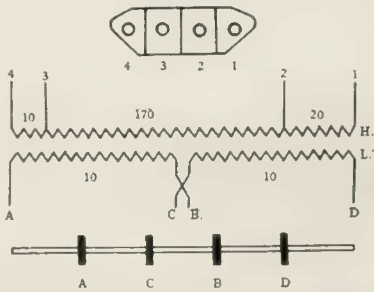


FIG. 2—DEVELOPMENT OF WINDING FOR TEST PURPOSES ON A 2 200 TO 220-110 VOLT, 60 CYCLE, MANHOLE TRANSFORMER

and numbering of terminals. Applying about 100 volts to the total high tension winding, the location and numbering of terminals is checked as in the example above. The most convenient voltage for use in checking the ratio of this transformer should be five volts per turn impressed on the high tension, as this voltage will enable the test to be completed with only one voltmeter. Apply 1 000 volts to the total high tension winding from *1* to *4*. There should then be 100

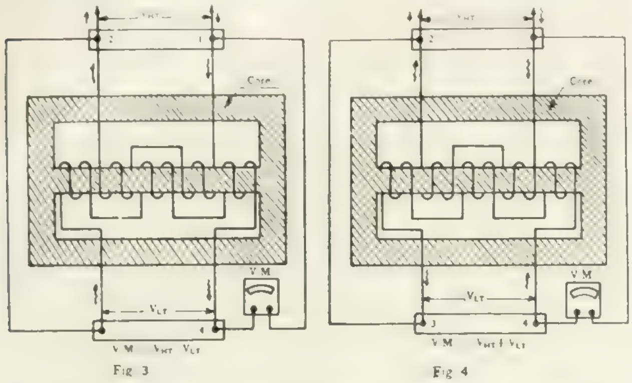
volts across the total low tenson winding. The taps on the high tension should be read as follows:

1 — 2 = 100 volts = 20 turns.
3 — 4 = 50 volts = 10 turns.

The ratio of the low tension taps should be checked by reading the voltage from

A to *B* = 50 volts = 10 turns.
C to *D* = 50 volts = 10 turns.
A to *D* with *B* and *C* connected = 100 volts = 20 turns.

As a general rule the ratio test can be made without immersing the transformer in oil. In exceptional



FIGS. 3 AND 4—DIAGRAMS SHOWING INSTANTANEOUS DIRECTIONS OF VOLTAGES FOR THE TWO POSSIBLE ARRANGEMENTS FOR POLARITY

The polarity shown in Fig. 3 is usually designated as negative, that in Fig. 4 as positive.

cases in which it becomes necessary to apply approximately normal voltage to a high voltage transformer the test should be made under oil. Extreme accuracy should be exercised in making these tests, as a small difference in ratio may cause circulating currents between transformers operating in parallel.

POLARITY*

Transformers are generally designed so that the instantaneous direction of the current in certain leads is the same in all transformers of the same type, in order that similar leads of different transformers may be connected together for parallel operation. In some cases it is standard practice to build transformers so that the instantaneous direction of current is that indicated in Fig. 3 In other cases, however, the standard is to have the polarity just the reverse of this, as indicated in Fig. 4. With the connections shown in Fig. 3, the potential stress between the voltmeter ends of the primary and secondary coils is less than with the connections shown in Fig. 4 by an amount equal to twice the secondary voltage. When the two coils are not connected, this difference is not so great, but the stress between primary and secondary is always less with the polarity as shown in Fig. 3, than with that shown in Fig. 4. The polarity test should be made while stepping out for the position and numbering of the terminals with a low voltage, as described above under ratio tests. The proper method of testing for polarity is to connect the highest numbered lead on the high tension to the lowest numbered lead on the low tension side, as indicated in Figs. 3 and 4. A low voltage should then be applied across leads *1* and *2* and a voltmeter having a range sufficient to indicate the sum of the high tension and low tension voltages should be connected across leads *1* and *4*. Then, with a transformer such as given in Fig. 3, the voltmeter should indicate the difference of the high tension voltages, as shown. Should the voltmeter indicate the sum of the high tension and low tension voltages, the polarity is that shown in Fig. 4.

Where a transformer is available whose characteristics are known, as is usually the case with distributing transformers, the polarity may be checked by connecting the transformer under test to the standard transformer, with the primaries in parallel and the secondaries in series, as shown in Fig. 5. If the secondary voltages as measured by the voltmeter are identical the ratio of the transformer under test is correct. If the two lamps light up, the polarity is correct. The transformer secondaries may also be connected in parallel, with the homologous leads on one side of the transformer connected together and lamps connected across the remaining two leads. In this case the lamps should remain dark if the polarity

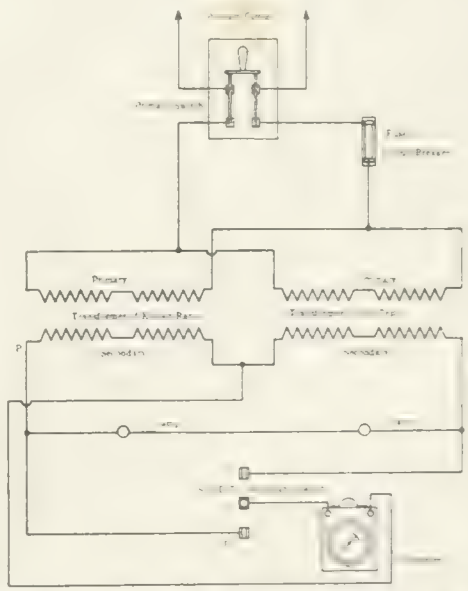


FIG. 5—CONNECTIONS FOR DETERMINATION OF POLARITY AND RATIO BY COMPARISON WITH A TRANSFORMER OF KNOWN CHARACTERISTICS

is correct. The objection to this latter method is that an open circuit will also cause the lamps to remain dark.

PARALLEL TEST

The parallel test is to determine whether there is any circulating current between parts of the transformer windings which are designed to operate in parallel. Should there be any error in the ratio of the parts intended for parallel operation it will appear in

*See article by Mr. W. M. McConahey, in the JOURNAL for July, 1912, p. 613.

the parallel test.* The method of procedure may be better understood from the following example of a transformer having two coils in the high tension winding which may be operated in parallel, and four coils in the low tension winding which may be operated in parallel.

The leads of the same polarity from all the coils in the low tension are connected together, as shown in Fig. 6, by connecting terminals *5*, *7*, *9* and *11* on the terminal board by means of the connectors provided for that purpose. Then connect one end of a fine wire to terminal *6* and the other end of the wire to the end of a clean dry stick (such as may be handled with perfect safety) in such a manner as to leave a short piece of wire free. Apply about ten percent of normal voltage to the transformer. The end of the wire should then be touched in succession to terminals *8*,

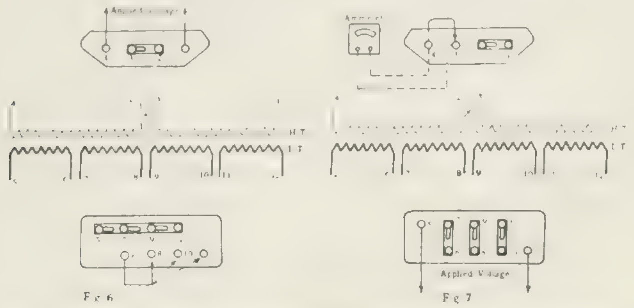


Fig. 6 Fig. 7

FIGS. 6 AND 7—DIAGRAMS SHOWING WIRING AND TERMINAL CONNECTIONS FOR PARALLEL TEST ON SECONDARY AND PRIMARY RESPECTIVELY

10 and *12*. If no spark is observed in any of the parallels normal voltage should be applied to the high tension and the operation should be repeated. Should a spark be observed in any parallel, an ammeter should be inserted in the circuit between terminal *6* and the terminal at which the spark was observed. The circulating current should not be great enough to cause objectionable heating. The ammeter used to read the circulating current should have a very small impedance drop, since otherwise its impedance may be sufficient to reduce the circulating current to a negligible value, whereas, the maximum value of the circulating current is sought.

The halves of the high tension should be tested for parallel in the same manner as the low tension, *i. e.*, terminals *1* and *3* should be connected on the terminal board, as shown in Fig. 7, and a low voltage should then be applied to the low tension in series and the terminals *2* and *4* touched together by means of the stick and wire. Should there be no spark, normal voltage should be applied to the low tension and the high tension tested again. Should a spark appear, the value of the circulating current should be determined as directed above. Care should be taken not to touch any two terminals together except those of similar polarity.

*In a shell-type transformer having a very long core, a small circulating current may flow, due to magnetic leakage, even when the ratios are exactly correct. This is in no way detrimental to the performance of the transformer, as it means only that a part of the core is being magnetized from the secondary.

MEASUREMENT OF RESISTANCE

In general, two methods are in use for determining the resistance of various windings:—The fall of potential or voltmeter-ammeter method, and the direct measurement by means of a suitable bridge.* Bridge methods on account of their convenience, rapidity and accuracy are to be used in all cases possible. For the very low resistances of large transformer secondaries, the fall of potential method is usually the only accurate method available.

Ordinarily, less difficulty is encountered in making exact resistance measurements, than in determining the temperature of the copper at the time the measurements are taken. Readings to determine the cold resistance should not be taken unless the transformer has been standing in a room for from four to twenty hours, depending on the size of the transformer, without any great change in temperature. Thermometers should be placed as close to the copper as possible, and in large transformers, at both the bottom and top of the windings, as the air is frequently warmer at the top. In oil cooled transformers the temperature of the oil is taken as that of the transformer, after it has stood for several hours.

When measuring resistance by the fall of potential method, the readings should not be taken until the current has reached its maximum steady value, which may require several minutes, as otherwise the induced e.m.f. produced by the changing flux will cause an error. In a high potential transformer, the direct current should be built up and reduced gradually by means of a rheostat, or other similar means, as any rapid change in current strength and corresponding flux, such as by opening a switch suddenly, may produce an excessive potential.

*See the JOURNAL for February, 1913, p. 145.

(To be continued)

Experience on the Road

A PECULIAR TRANSFORMER CONNECTION

L. M. KLAUBER

THREE 75 k.v.a. transformers connected in closed delta were installed to furnish power for an amusement park having a total connected load of 240 horse-power, in three-phase induction motors. The transformers were installed as a step-down bank reducing the voltage from 11 000 to 460.

At the time the transformers were first placed in service, the park was just beginning operations and the total connected load was somewhat under 50 horse-power, with a rather low demand factor. At this time the service appeared excellent but gradually as the various concessions were put into operation it was noticed that the regulation on the 460 volt secondaries was poor; and finally, when an attempt was made to put normal load on the 100 horse-power cage-wound motor operating the scenic railway, the secondary voltage fell to approximately 200 volts at the substation switchboard and the transformers heated very rapidly.

A hurry call to the central station supplying the power brought out some investigators equipped with instruments and confidence. But the problem was not solved as quickly as was expected. It was thought at first that a simple case of a blown fuse and an attempt to run the motors single phase would be found, but preliminary tests showed 460 volts across each phase of the secondary and, as no motors were operating, it was seen that both primary and secondary fuses must be intact since no other condition could produce even an approximate triangle of voltages on the secondary.

The external wiring was then checked and found correct. The motor loads were tested and found to be within the rated capacity of the bank. Tests were then made by means of "split ring" current transformers and ammeters for circulating currents in the primary and secondary deltas and for abnormal currents in each transformer, but without result. The voltage on the 11 000 volt incoming line was investigated by means of the single-phase bank supplying light to the park, and it was seen that the poor regulation did not exist in the primary lines. Attempts were made to run in open delta with each transformer cut out, but there was no improvement. In fact all conditions appeared normal except for the very evident fact that the transformers, although giving proper voltage and perfect service at light loads, absolutely refused to carry loads considerably below their rated capacity.

The complete voltage rating of the transformers was 11 000—10 500—10 000 to 2 300—460, the change in secondary being made by copper links in the usual way. The electrician who had installed the transformers insisted that the internal connections were correct; nor was it seen how conditions could be otherwise without causing either a short-circuit, an open circuit or at least an incorrect secondary voltage. However after all theories and tests had failed to locate the trouble, an investigation was made of the terminal board two feet under the hot oil, and the cause of the trouble was at once evident. Two of the links were missing.

The secondary connections of a single transformer are shown in Fig. 1-*a*. The missing links were the larger ones shown by broken lines. It afterwards developed that they had not been shipped with the transformers, and it will be noted that they are not necessary when connecting the transformer for a secondary voltage of 2 300.

The peculiar result of normal voltage at light loads and very low voltage even at loads considerably

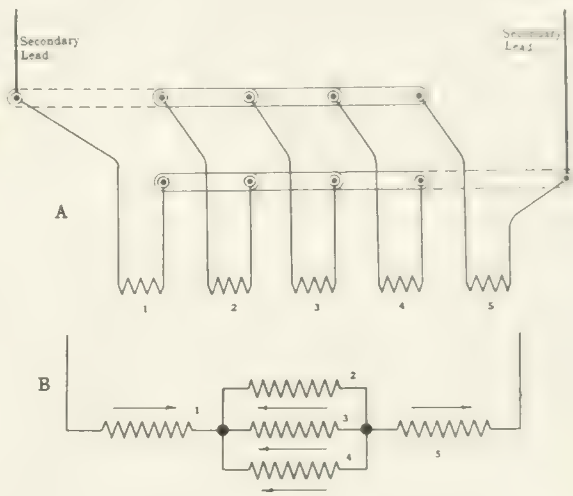


FIG. 1

below rating, will be clearly seen in Fig. 1-*b*, which shows the voltage relations of the individual coils. Coils *2*, *3*, and *4* in parallel with each other are in series with coils *1*, and 5, but the voltage across *2*, *3* and *4* (460 V.) is in opposition to that across *1* and *5* totaling 920 V. thus leaving a resultant across the transformer of 460 or normal voltage.

But when full rated load (at 460 volts) is put on the transformer with this connection, coils *1* and *5* are each carrying five times full load current, while coils *2*, 3 and *4* each carry five thirds of the rated load. As might be expected the drop across coils *1* and *5* is very great and although it is also considerable across *2*, *3* and *4*, these coils do not suffer so much, so that the net voltage across the transformer terminals falls off considerably as was noted. The cause of the heating is also apparent.

After the missing connectors were installed the transformers gave no further trouble. It was considered fortunate that these transformers withstood this difficult service without permanent injury.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1041—Testing Automobile Generators—Please outline a set of tests to make on automobile lighting generators and starters, so as to enable one to make comparative tests of the different makes. P. J. (OHIO)

The most satisfactory method of making a bench test on a starting motor is to make an ordinary brake test with the motor connected directly to the storage battery with which it will be used. Storage batteries of from 80 to 120 ampere hours are commonly used, the size depending on the size of the engine to be started. The motor should not be connected directly to the storage battery terminals, but should have approximately the same length of wire in circuit as it will have when the outfit is assembled on the automobile. Ten feet of 85 000 cir. mil cable is a fair average for use with the smaller size batteries. With the larger batteries, larger cable should be used. The motor should have sufficient heat capacity and temperature rating to completely discharge a fully charged battery. Regulation curves giving the output and voltage of the generators at speed ranges from zero to a car speed of 45 miles an hour should be taken. The actual generator speed depends on the gear ratio of the engine and the speed of the generator in relation to the speed of the engine. The generator should have a continuous rating at a car speed of approximately 30 miles per hour, and when operated continuously at this speed should not reach a damaging temperature. It should balance the lamp load at approximately 15 miles per hour or less. The generator can very easily be operated through the necessary speed range by belting to any small driving motor. If the efficiency of the generator is desired, it can be taken either by the separate loss method or by the input-output method. One of the most important features in comparing automobile generators and motors of different makes should consist of a careful mechanical inspection of the different parts to determine whether the parts have been correctly proportioned for the work they are called upon to do, so as to give a reasonable assurance of long life in operation. C. T. W.

1042—Vector Relations in Unbalanced Circuit—An unbalanced load is delta connected as shown. Is it correct to say that a triangle with sides proportional in length to the three voltages shows correct phase relations of the voltages? If so, where is this explained? D. E. C. (PENNA.)

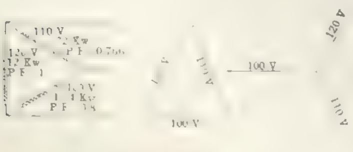


FIG. 1042 (a)

A triangle constructed with its sides proportional in length to the voltages as in Fig. 1042 (a) gives the correct phase relation of the voltages. It is convenient for the purpose of obtaining the currents in the line to transfer the sides of the triangle thus constructed to a radial vector as shown. This is explained in an article by Mr. Chas. H. Porter in the JOURNAL for September, 1907. J. F. P.

1043—Two-Phase to Three-Phase Transformer Connection—Please discuss the method shown in Fig. 1043 (a) for changing from two-phase to three-phase or vice versa by using three standard transformers. C. W. F. (OHIO)

This is the same connection as is shown in No. 959, published in the JOURNAL for September, 1913, except

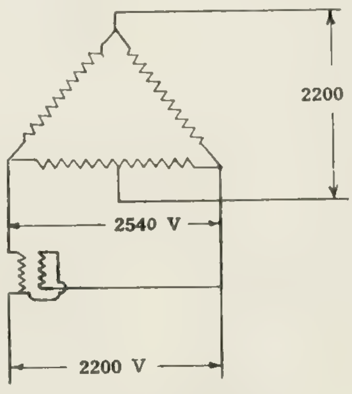


FIG. 1043 (a)

that the small auxiliary transformer has two separate windings instead of being an auto-transformer, and is connected to buck the voltage in the high phase of a two-phase circuit instead of to boost the low phase. The results will be equally satisfactory, provided the voltages secured are the same, which will depend upon the relative potentials of the main and the small auxiliary transformers. C. R. R

1044—Constant of Graphic Wattmeter—A five ampere, 110 volt, three-phase graphic wattmeter is used with 100 to 1 current transformers and 4 to 1 potential transformers. The chart used has a maximum capacity of 1 000 kw. In figuring the constant *X*, which of the following methods are corect?

(a) — $\frac{100 \times 4}{1\,000} = 0.4$ as constant.

(b) — $\frac{500\text{ A} \times 440\text{ V.} \times 1.732 \times \text{P. F.}}{1\,000}$ $\div 1\,000 = X$.

R. W. W. (IND.)

It is easy to become confused between methods of calculating and methods of measuring three-phase power. The power in a three-phase circuit $= \sqrt{3}\,EI$, where *E* represents voltage between conductors and *I* represents the current in each conductor. This formula is derived from the fact that the total power in watts necessarily is equal to the sum of the watts transmitted through each conductor. The watts transmitted through each conductor $= eI$ times the power-factor where $e =$ the voltage between conductor and neutral $= E \div \sqrt{3}$. The sum of the watts in the three conductors $= 3\,eI$ times the power-factor $= \frac{3\,EI}{\sqrt{3}} \times \text{P.F.} = \sqrt{3}\,EI \times \text{P.F.}$ Measuring power with a polyphase wattmeter corresponds with the two-wattmeter method of measuring power with single-phase wattmeters, the only difference being that the meter automatically adds or subtracts the readings of the single-phase elements by means of the mechanical connection between them. The total load is the algebraic sum of the single-phase wattmeter readings. Hence, the total load indicated by a polyphase wattmeter is twice the load corresponding to the reading of one of its single-phase elements at unity power-factor. The constant of 0.4 obtained in formula (*a*) is correct. A convenient rule for general application in checking the calibration of polyphase wattmeters is: The reading corresponding to a given load in the meter itself should be equal to twice the product of primary amperes and volts necessary to produce that load in the secondaries. For example, if the transformer ratios are $500 \div 5$ amperes and $400 \div 100$ volts the meter reading at 500 watts per element should be $2 \times 500 \times 400$ equals 400 000 watts or 400 kilowatts. H. B. T.

1045—Induction Motor Trouble—We have a 186 horse-power, 2 200 volt, two-phase induction motor, driving two 100 lamp brush arc generators which has been giving trouble. The current jumps from one coil to another, generally, but not always, from one phase to another, or from a coil to ground. Only in one case has the burn been in a slot, and very seldom between coils where they touch each other. The trouble is generally near the ends of the coils where the connections go from one to another and where the coils are separated from each other. When the current jumps to ground it is usually from the under side of a coil to the frame, a distance of over one-half inch. Some times this does no more damage than to burn off a spot in the insulation and again it may burn off two wires of the turn of a coil. There are six coils per pole and the trouble has always been within the four poles or twenty-four coils nearest the motor terminals. The motor runs hot even when driving only one generator, but gives less trouble than when driving both. After being repaired it may run for two weeks or

it may show trouble in a few hours. Another motor of the same kind but of half its capacity gives no trouble at all. Should the two adjacent coils of opposite phases have higher insulation than the other coils and are these called the "phase coils?" C. W. F. (OHIO)

Not knowing all of the details of the construction and the insulation of the motor, we can only make the following suggestions: The insulation on the coils may have been bruised or damaged when the coils were being wound into place. Since the motor runs hot even when driving one generator, the insulation may have become deteriorated. Then the breakdown may be caused by "creepage" from one phase to another across the phase coils due to dirt or moisture, and not break down between the two coils between which the phases change, because they are better insulated. The trouble may also be due to the brush arc generators, and if their frames are not grounded, it would be advisable to ground their frames or else the frame of the motor. Lightning and other high voltage disturbances usually cause grounds or short-circuits on those coils which are connected close to the terminals. Your trouble may be somewhat similar. These disturbances break down the insulation at the weakest point and, therefore, would not break down the insulation of the other motor if it is not running hot. The two adjacent coils of opposite phases should be better insulated (for motors of this size and voltage) than the other coils and are usually designated as "phase coils." J. L. R.

1046—Paralleling Scott-Connected Transformers—What tests should be made with a voltmeter or lamps to determine whether the secondaries of the two sets of three-phase to two-phase Scott connected transformers, Fig. 1046 (a) can be operated in parallel? P. J. (OHIO)

In order to make polarity tests, connect transformers as shown in Fig. 1046 (b), being very careful to see that both groups are symmetrically connected to the three-phase circuit. This means that terminal *1* of main transformer No. 1 must be connected to the same line wire as terminal *1* of main transformer No. 3. The same

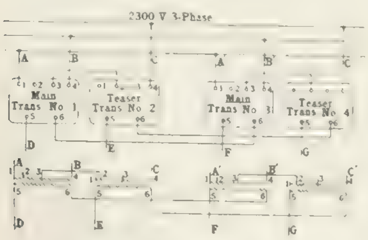


FIG. 1046 (a) AND (b)

applies to all other connections. Unless the transformers are correctly connected in this respect, they cannot be made to parallel. After the three-phase connections are checked, connect the two-phase sides as shown. Then, if all connections are correct there will be no voltage between *D-E* and none between *F-G*. If, however, one of these should measure 220 volts, it shows that one of the two low tension windings is reversed. It is only necessary then to reverse the connections of one low tension winding. After connections have been made so that there is no voltage between *D-E* or *F-G*, connections for parallel operation can be made in the usual way, paralleling the windings of transformer No. 1 with No. 3 and No. 2 with No. 4. W. M. M.

1047—Regulating Moving Picture Arc Lamps—A 125 volt, 88 ampere compound-wound generator furnishes power for a moving picture arc lamp, taking from 50 to 75 amperes at about 65 volts. Two rheostats, rated at 110 volts, 22 to 40 amperes in multiple, are connected in series with the positive side of the lamp. The drop across these is 47 volts. Either three-fourth or five-eighth inch carbons are used; the common practice is to use three-fourth inch upper carbon and five-eighth inch lower. In all the other houses having similar machines either hard or soft carbons can be used and the lamps burn with a white flame between carbons. On this machine only soft carbons can be used and the arc burns with a large flame at an angle with the carbons, as in Fig. 1047 (a). The flame travels all over the positive carbon but remains stationary at one point on the negative carbon.

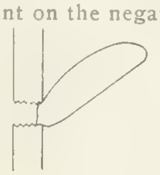


FIG. 1047 (a)

There are no magnets in the room to blow the arc. We have tried hard and soft carbons of different makes with the same results. We have put resistances in parallel with those in the circuit; have put resistances in both negative and positive side of the lamp; have cut down current and the voltage, but the carbons still flame. With the voltage on the generator at 115 volts, the lamp takes about 65 amperes and the voltage does not vary. But if the generator is adjusted by aid of field rheostats to 80 or 90 volts, when the lamp is started, the voltage on the generator rises to 105. Is there any way we can get rid of the flame to give us a straight arc? Sometimes the flame is so intense as to burn the enclosing casing. The carbons are set in a straight line, but on the slant. C. S. (ALBERTA)

It would appear that there is a decided blowing of the arc caused by a magnetic field. Try turning the lamp around and note whether the blow is in the same direction as before. This will show whether the magnetic field comes from the lamp itself or from some outside source. If it is seen that the "blow" comes from the lamp itself, look for wires carrying current in the neighborhood of the arc and remove them—or it may be that the magnet coil (if it is an automatic feed lamp) is the cause of the field. To determine this, short-circuit the coil and feed the lamp by hand or reverse the coil and note the effect on the arc. If it is seen that the "blow" comes from the outside, see that all rheostats are placed at some distance from the lamp. See that leading in draughts will, of course, blow an arc wires do not pass near the arc. Air and should be prevented. The blow—if magnetic—may be stopped by placing a bar magnet in or near the lamp, the position to be determined by trial. This is done in many arc lamps commercially. G. M. L.

1048—Changing Voltage of Direct-Current Motor—I have a 60 horsepower, 500 volt direct-current motor having six shunt poles, six commutating poles, six sets of brushes, 79 armature slots, 158 commutator bars. The motor is of the variable speed type rated at 325 to 650 r.p.m. by field control. It is belted to a compressor for refrigerating purposes. I wish to change this machine for 230 volt operation. The armature at present is wave wound, with two coils per slot. Could the armature be re-connected from wave to lap connection and operate satisfactorily? W. [illegible]

This armature may be reconnected for 250 volts by connecting the two coils per slot in parallel, but the connections of the coils to the commutator will have to be changed. In winding the armature as it is wound at present, when the third coil is put on the armature, its lead is connected to either the commutator bar before or the bar after the one from which the start was made. In connecting the coils in parallel instead of bringing the lead of the third coil to the adjacent coil this should be skipped over and the lead connected to the second bar beyond. In this manner every coil lead will be shifted over one bar. The two coils in the same slots may then be connected in multiple by joining adjacent commutator necks. With the armature so connected, the main field coils and commutating coils may be connected in series—parallel. When run on 230 volts this combination would probably be slightly lower in speed than at present. The low speed may be taken care of, however, by a slight increase in air-gap. This would be the best way of changing this motor for operation on 230 volts. The number of slots in a multiple wound armature should be either divisible by the number of poles or the number of pairs of poles, in order that there may be no possibility of circulating currents. For the power output and speed the commutating constants will be approximately the same for the two-circuit and multiple-wound armature, and the power output will be the same if the voltage is lowered to obtain the same speed as that of the two circuit machine. C. G. L.

1049—Three Wire Rotary Converters—We have a six-phase rotary converter direct connected to a turbo-generator. We desire to mount slip rings connected to the commutator of the rotary converter and from them to auto-transformer balancers in order to obtain the neutral for a three-wire circuit. Please give method of determining the size of leads from the slip rings to the transformers, for three, four or six rings. Please give distribution of currents, assuming an unbalancing of 25 percent on the three wire circuits. P. F. A. (AUSTRALIA)

The alternating-current collector rings can be used instead of equipping the machine with additional rings as mentioned. For six rings, three bal-

ance coils would be necessary, connected as in Fig. 1049 (a). For three rings on a six phase machine, three balance coils would also be necessary, connected as in Fig. 1049 (b). Four rings could not be used without bringing out special taps, because on a six-phase machine the taps on the armature to the collector rings are 60 degrees apart. In order to use three-wire connections with four rings, taps would need to be made at *A* and *B* Fig. 1049 (c) in quadrature with taps *1* and *4*. Two rings could be used on a six-phase machine with a single balancing coil, connected as in Fig. 1049

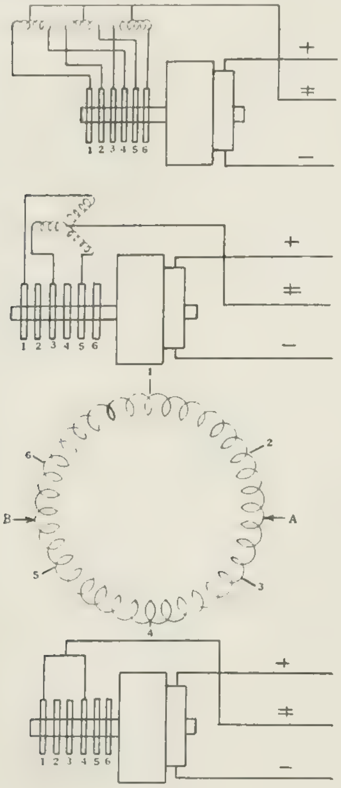


FIG. 1049 (a), (b), (c) AND (d)

(d) but this method does not give quite as easy operation as the use of a larger number of coils. Assuming x equals the full-load direct current of the converter, then the unbalancing of 25 percent would mean x divided by 4 (amperes flowing in the main neutral wire). The amperes per lead between collector rings and balance coils would, therefore, be:—For six rings, $\frac{x}{4 \times 6}$; For three rings, $\frac{x}{4 \times 3}$. For two rings, $\frac{x}{4 \times 2}$. To these values of current sufficient additional allowance should be made to cover the magnetizing current required by the balancer coils. R. H. N.

1050—Belt Slippage—In factories ranging in size from 50 to 250 horse-power using belt and line shaft transmission from the engine, what percentage of the power plant investment would you estimate to cover the cost of transmission equipment; to include all belting, shafts, etc., for setting up? (b)—In a planing mill of 175 horse-power where shaft transmission from an engine is used and the drives well proportioned, what percent slip is met in practice between the engine and the shaft of the machine driven, considering three belt conversions? F. C. F. (WEST VIRGINIA)

Little confidence could be placed in figures to estimate the cost of transmission equipment, if based on the plant horse-power, because the amount of transmission material necessary has no relation to the power plant capacity except in some particular variety of industry. A better method is to determine approximately the number of lineal feet of shafting that will be required. Figures at hand give from $2.00 to $6.00 per lineal foot including cost of shafting, hangers, couplings and pulleys. Another rough rule is to allow $1.00 per lineal foot per inch of shaft diameter. In machine shops, in which industry approximately the same conditions exist everywhere, $25.00 per horse-power is a pretty good figure to cover transmission investment cost. (b)—If the questioner refers exclusively to slippage, we have no figures available, but the total friction losses met with in woodworking plants are found to vary between 20 and 50 percent. In a sash and door factory having a 100 horse-power engine and an average indicated load of 51 horse-power, the friction losses were found to be 40 percent from the engine to the machine pulley. A very excellent treatise on belt slippage was presented at the September, 1911, convention of the National Association of Cotton Manufacturers by Professor W. M. Sawdon, of Cornell University. See also articles on "Comparison of Group and Individual Drive in Machine Shops," by A. G. Popcke, in the JOURNAL for November, 1911, page 999. A. F. S.

1051—Power Transmission—What would be the cheapest and best way of delivering 75 kw at 80 percent power-factor, 400 volts, three-phase, 25 cycles, 3 500 feet from the plant, where the generated voltage is 440? What would be the difference in cost of transmitting at 400 or 1 100 volts, power to be delivered at 400 volts? Please give example. R. L. W. (PENNA.)

The voltage should be stepped up to at least 2 200 and preferably to 6 600 volts, as the saving in copper at 6 600 volts will compensate for the slight increase in cost over 2 200 volt equipment and the line losses will be reduced approximately 77 percent. The voltage regulation will also be greatly improved, and, if 6 600 volt transmission adopted, the power transmitted by the line may be considerably increased at a later date, if desired, without increasing the amount invested in the line. Comparative figures for the various voltages are given in the following table, all values being based upon the 6 600 volt equipment as 100 percent. At 400 volts it would be necessary to split the copper into several circuits in order to avoid execessive reactance drop, which would also increase the installation costs above those for the other voltages, a feature not considered in the table.

	6600 v	2200 v	400 v
Conductors per phase........	1 #4	1-#1	12 #0000
Voltage regulation, percent.	2*	9*	11
Cost of copper, percent.	6.7	12.9	562
Cost of transformers, percent	93.3**	89.1**	......
TOTAL	100.0	105.0	562

* Exclusive of transformer regulations

** Based on three single phase transformers at each end of line.

A. D. H.

1052—Starting Synchronous Motor—Should a 500 horse-power, three-phase, 2 200 volt synchronous motor started by means of an auto-starter having three sets of taps for 440 volts, 880 volts and 1 600 volts, be at synchronous speed before the field and running switches are closed? J. T. K. (ONTARIO)

Under ordinary starting conditions, the synchronous motor should come up to synchronous speed on the lowest starting voltage. Ordinarily, it is not necessary to use more than one starting voltage since with proper field excitation the voltage can be changed from the starting voltage to normal voltage with less current than occurs on the application of the starting voltage. The motor should be in synchronism before the field and running switches are closed if minimum starting current is to be obtained. In a few applications the torque required during the starting period has been so large that it requires practically full voltage to bring the motor up to synchronous speed. In such cases obviously the motor cannot be in synchronism before line voltage is applied. This, however, is a more severe starting condition than is usually encountered with synchronous motor applications and is not to be recommended. The synchronous motor will pull into step on light loads before the field switch is closed, the necessary excitation for synchronous running being supplied by wattless current in the armature winding. In other cases, involving larger loads, the motor will hunt slightly either side of synchronous speed without field excitation and will operate steadily at synchronous speed only when the field switch is closed. For a detailed explanation of synchronous motor performance during starting, see proceedings of the A. I. E. E., June, 1913. F. D. N.

1053—Electrolytic Lighting Arresters—An electrolytic lightning arrester is like a safety valve and up to a certain point checks any flow when connected correctly. What happens if it is connected up backwards? When charging an electrolytic arrester on a three-phase, one 3 000 volt alternating-current line, each line is connected to ground. Does the current flow in one direction only? C. F. P. (TORONTO)

An electrolytic lightning arrester or cell when connected to direct-current, has the film formed on one plate or tray only and if the connection is reversed there will be a heavy flow of current which will decrease as the film is built up on the other plate. This flow of current occurs because the film opposes the flow of current only from the aluminum to the electrolyte and not from the electrolyte to the aluminum. If the cell or arrester is connected to an alternating current instead, the film wil be formed on all the plate or tray surfaces which are in contact with electrolyte and which have electromotive force impressed across them. During one-half cycle the film will be built up on one plate of a cell and on the other plate during the succeeding half wave. It will make no difference if the leads are reversed. When an electrolytic lightning arrester connected to an alternating-current circuit is charged, the current will flow in one direction during one-half cycle and in the reverse direction during the succeeding half cycle in the same manner as in any alternating-current circuit. G. C. D.

THE ELECTRIC JOURNAL

VOL. XI MAY, 1914 No. 5

The New Method of Distribution on the New Haven Railroad

The circuit between the power house and locomotive or car is the dominant factor in the electrification of railways. In an ideally simple system, a trolley wire conveys the current from the generator bus-bars to the contact on the locomotives. This simple method has been in operation for nearly seven years on the New Haven Railroad. The orthodox method for utilizing a higher transmission pressure is by means of raising transformers, high tension lines and lowering transformers in sub-stations for supplying current to the trolley wires. The new distribution system of the New Haven Railroad, as described by Mr. Arthur in this issue of the JOURNAL, employs the several elements of a complete system in a modified form in fact, so modified that they are scarcely recognized. The primary and secondary windings of the transformers are not separate and independent, but a part of the coils are used in common by the two circuits. An "auto-transformer," raising the pressure from 11 000 to 22 000 volts, has twice the output that the same material would have if the circuits were separate. The lowering or sub-station transformers are likewise auto-transformers with a similar advantage in output.

An analogous combination is made in the circuits. The transmission circuit and the secondary circuit are not independent, but the trolley wires serve in common for supplying current to the locomotives and as one of the conductors of the transmission circuit. Viewed in another way, a three-wire system with 22 000 volts between outside wires (the trolley and feeder) is loaded on one side only, between the trolley and the track which serves as a middle wire. The auto-transformers along the line are similar to balance coils, the middle points of which are connected to the track. Sub-stations are usually buildings at considerable intervals containing transformers and other appliances; here the transformers are of the outdoor type and are located at short intervals.

This is a simple method of transmission which seemed to be well adapted to the conditions of the New Haven road. The radius of transmission with a limiting line drop is extended by employing 22 000 volts, but without exceeding more than 11 000 volts between conductor and earth. As all of the transmission current is carried on overhead conductors, the induction in adjacent circuits is practically eliminated. This result is secured by placing the conductors so that the outgoing and return currents have the same mean position. The mean position of the trolley wires is over the center of the tracks and the other side of the circuit is divided into two parts which are placed on the right and the left of the tracks.

While the use of the trolley wires for transmission as well as locomotive supply has proved to be the effective method of extending the electrification to New Haven and of modifying the circuits in the zone which has been in operation so as to avoid the interference with telegraph circuits which increased load might have caused, nevertheless, it cannot be regarded as a method for universal application. In most cases where a higher pressure than that of the trolley wire is employed, it will be desirable to go higher than 22 000 volts. In case of accident there are some advantages in having the transmission system independent of the trolley circuits. However, for the conditions of the New Haven Railroad, the auto-transformer and the combined circuits have many unique features which have adapted them in a very successful manner to the operation of this notable electrification.

CHAS. F. SCOTT

Synchronous Booster Rotary Converters

The synchronous booster rotary converter is not a piece of apparatus new to the electrical business, as it has been in use for several years and there are many thousand kilowatts of rotary converters of this type giving satisfactory operation today. However, it is a type of apparatus not generally known. Indeed, very few, perhaps, aside from those whose work brings them in contact with it are familiar with this form of rotary converter.

As is well known, the first rotary converters were used where a constant voltage supply was required and, since the ratio between alternating and continuous voltages is practically constant, the rotary converter is inherently incapable of voltage regulation, except within very narrow limits. The synchronous booster principle was developed and applied to rotary converters in fields where a variable continuous voltage is necessary. This type of rotary converter is very extensively used on 25 cycle systems feeding Edison three-wire networks and has been used to a limited extent in some industrial applications. In fields other than these, the synchronous booster rotary converter has until re-

cently been practically unknown. On 60 cycle systems in particular, where companies have Edison three-wire networks as part of their systems, the converting agent has heretofore been the motor-generator set. With the advent of the improved 60 cycle rotary converter, utilizing both better design and operating characteristics, reliability of operation is practically assured and operating companies are becoming more and more inclined toward 60 cycle converters. From the improved 60 cycle rotary converter of the constant voltage type, it is but a step to the synchronous booster type and, in this unit, the central station companies have a means of feeding their direct-current systems by a converting agent very superior to the motor-generator set from the standpoint of economy. There will be several points in favor of the rotary converter outfit in efficiency at full load and, since the efficiency curve of this apparatus is much flatter than that of the motor-generator set, the difference is more apparent if the load-factor be low.

The article by Mr. J. L. McK. Yardley, which appears in this issue, describes very clearly many important features of the synchronous booster rotary converter and should be the means of making the electrical fraternity in general fairly familiar with this improved type of apparatus. The application of commutating poles to the synchronous rotary converter has been carefully worked out from the designing standpoint and practical operation has demonstrated that the designer has worked in the right direction. The article brings out the undesirability of attempting to operate rotary converters under load at low power-factors, demonstrating what is well known generally, namely, that the rotary converter is not suitable for operation as a synchronous condenser.

The mechanical arrangement of the booster with reference to the main rotary converter has gone through several stages of development. The present article points out why the modern machines are built with revolving armature boosters, and with the booster located between the collector rings and the armature of the converter, rather than attempting to use standard rotary converters and attaching thereto standard alternating-current generators to be used as boosters.

E. P. Dillon

Speed Control of Induction Motors The description of a method of regulating economically the speed of induction motors by Mr. G. E. Stoltz, in this issue of the Journal, suggests the general question as to which is the best method of accomplishing this result. The arrangement described has been successfully operating for some time so that there is no question as to its reliability. It is not, however, the only method that is in practical operation, as there are a large number of schemes which use a three-phase commutator motor in some form or another. A number of such installations are operating successfully in Europe, but up to the present no actual experience has been gained in this country. The transplanting of a new piece of apparatus from Europe to America has not always been attended with success unless changes have been made to adapt it to the different operating conditions. In general it may be stated that the demands on machines in America are greater than in Europe, as the operators pay less attention to them, and also due to the fact that engineers in this country have been educated to expect greater reliability and simplicity than in Europe, where attendants are usually better trained technically. This is evidenced by the marked difference in the construction of standard lines of machines. For instance, European induction motors almost invariably have had wound coils and lighter mechanical construction, compared to the standard practice in this country of form wound coils and a mechanical construction at least fifty percent stronger. Consequently the European motors are considerably lighter and somewhat cheaper, but they are not comparable, from an operating standpoint, with the American machines. In view of these facts, it is always questionable what results will be obtained with new European apparatus, no matter how glowing the report may be of its operation in the land of its birth.

The arrangement described by Mr. Stoltz has the great advantage of using machines, the characteristics of which are familiar to practically all operating men and which have been developed under American conditions. In fact the scheme is only a new combination, as far as this country is concerned, of standard machines, so that there can be no question as to the success of the arrangement as long as reasonable engineering care is taken in laying it out. The article brings out some characteristics of the combination that are interesting, such as power-factor correction and the possibility of running the induction motor above synchronism.

The problem of economical speed regulation of induction motors is of considerable importance in many industries. Briefly, it consists of taking energy from the rotor circuit at a low frequency and disposing of it with a minimum loss, in such a way that a reasonably constant speed is maintained. The various arrangements that have been used up to the present time are all open to the objection that they are complicated and expensive. The possibilities, however, have not been exhausted, and further developments are to be expected which will simplify the auxiliary apparatus required.

Wilfred Sykes

The Operation of the Single-Phase Equipment of the New York, Westchester & Boston Railway Company

R. R. POTTER,
Superintendent of Equipment
New York, Westchester & Boston Railway Company

THE New York, Westchester & Boston Railway Company commenced the operation of its passenger service May 29, 1912, from 180th street and Bronx Park to New Rochelle, a distance of 7.8 miles, and on July 1st, of the same year, extended the service from 180th street to White Plains, a distance of 15.13 miles. On August 3, 1912, the service was extended from 180th street to the Harlem River Terminal of the New York, New Haven & Hartford Railroad, a distance of 4.43 miles.

FIG. 1—N. Y. W. & B. RY. 11 000 VOLT, 25 CYCLE, SINGLE-PHASE MOTOR CAR

Showing arrangement of middle and vestibule side doors. The twin motors are carried on the truck at the right-hand end; the other truck is without motors. With all electrical and braking equipment installed, the appearance of the car indicates its light, open, yet substantial construction. The control is arranged for multiple operation in trains.

The car equipment consists of 30 multiple-unit cars, one electric locomotive, one gasoline electric work car and five freight cars. The multiple-unit cars are all steel, 72 feet long, weigh 120 000 lbs. and have a seating capacity of 78 people. They are capable of a maximum speed of 56 miles per hour, the speed being restricted to this through the action of an over-speed relay which automatically opens the control circuit when that speed is reached. They are equipped with two Westinghouse No. 409 B motors per car and Westinghouse electro-pneumatic control. The electric locomotive is used for all switching purposes around the yards and for the hauling of freight. It is of Baldwin-Westinghouse design and build, weighs 160 000 lbs. and is equipped with four Westinghouse No. 410 motors and Westinghouse electro-pneumatic control. The gasoline electric car is used for general line work.

FIG. 2—A TEN CAR TRAIN JUST NORTH OF THE EAST THIRD STREET STATION

Both the control and brake equipments were designed for use on trains up to this length.

FIG. 3—VIADUCT SOUTH OF THE 180TH STREET BRONX PARK STATION

The operating conditions have been peculiar in that a frequent service is demanded under practically steam road operating conditions, it being necessary to maintain the equipment to steam road standards. Trains are run under a twenty minute headway from White Plains and New Rochelle and a ten minute headway on the main line. The nineteen months of its operation have been very interesting and the results show the wisdom of the engineers in adapting the single-phase system. The equipment has thus far proved reliable and the cost of maintenance compares very favorably with similar heavy direct-current equipment. A number of defects and troubles developed early in the operation but were no more than were to be expected from new equipment and were easily remedied as soon as the cause of the trouble was located. Considering the comparatively small number of single-phase installations and the short time in which the system has been developed for railway service, it is remarkable that such excellent results have been obtained.

To those who have not had experience with the operation of equipment using high voltage, there is a tendency toward a feeling that it is more dangerous than other systems. There has, however, been an entire lack of this feeling among both the

shopmen and trainmen on the "Westchester," notwithstanding the fact that they have been required to go upon the roofs of cars and close to the high tension trolley numerous times. The safety of the

NEW YORK, WESTCHESTER AND BOSTON RAILWAY CO.

This Copy to Inspection Shop Foreman

Report of Defects to Car No. ....

Date.......................191 Line ....

........A. M. ....P. M.

Length of Detention..........Min's. Train No..........

Place of Trouble...

Motorman ....No..................

Conductor ....No..................

Car Body Troubles	**Control Troubles**
Bad Order Door...........	Circuit Breaker ....
Broken Glass	Circuit Breaker Re-Set......
Ventilator	Switch Group ....
Bell	Controller ....
Bell Cord..................	Reverser ....
Light Switches	Motor Cut Out.............
Markers	Current Limit Relay........
Heaters	Potential Relay ....
Diaphragm	Resistance Grids ....
Safety Chains	Jumpers ....
Buffing Device	Receptacles ....
Draw Bar	Blower Motor ....
Headlight	Motor Generator ....
Car Seats	Storage Battery Switches....
Car Floor Dirty............	Would not notch up.........
Lights	**Air Brake Troubles**
Pantograph Trolley.........	Brakes do not release quickly at times................
....	Brakes release on lap.......
Motor Troubles	Brakes do not stop train quickly enough............
Motor Bearings..............	Motorman's Valve stiff......
Motors Hot..................	Feed Valve ....
Gears	Governor does not cut out...
Truck Troubles	Compressor not working....
Motor Truck	Electric Brake ....
Trailing Truck	Brake Pipe ....
Flat Wheel	Reservoir Pipe Hose ....
Hot Box	Brake Pipe Hose............
Broken Brake Rigging.......	Air Whistle ....
....	....
....	....

Dead Car..

REMARKS:

....

....

FIG. 4—FORM USED BY TRAINMEN IN TURNING IN CAR DEFECT REPORTS

system in connection with danger to operators is shown by the fact that during the nineteen months of operation not a single trainman or shopman has been burned or shocked by the high voltage. It may also be interesting to know that all of the trainmen and shopmen had previously no experience with alternating-current apparatus, having had all of their experience on either direct-current or steam roads. The general results tend to show that there are no peculiarly difficult operating conditions with the use of the single-phase system. As stated before, the time spent upon the development of this equipment has been small compared with that spent on direct-current apparatus, and future developments will undoubtedly tend to increase its efficiency and reliability.

One large item of maintenance will be noticed in connection with the pantograph trolleys. This was excessively high until the trolley wire and track had been properly lined up. At present the breakages are very few and the mileage of the contact shoes has increased from 600 to 2 500 miles. This increase of mileage is attributed mostly to the fact that the contact surface of the trolley wire has now become worn flat. The wire, which is steel, is of the standard round grooved section, and, when new, presents only a line contact to the trolley shoe. As the pressure per unit of area when the wire is new is very great between the shoe and wire the wear is very rapid, but as the wire becomes worn flat a much greater area of contact is presented, greatly increasing the life of the shoes. The trolley wire now has a flat surface worn about 1/8 inch wide. Practically all of the wear on the shoe is due to the sliding friction of the shoe on the wire, the current handled by the shoe being so small that no burning takes place. It has been interesting to note that plain mild steel shoes give considerably greater mileage than galvanized iron shoes.

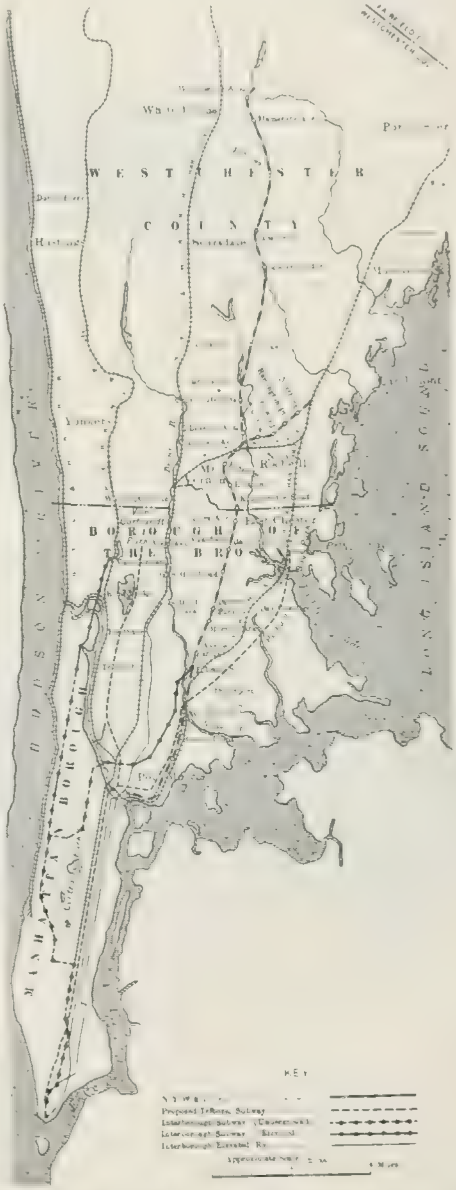


FIG. 5—MAP OF NEW YORK CITY AND SUBURBAN DISTRICT NORTH

During the warm weather the pressure of the shoe against the trolley wire is adjusted to between five and ten lbs. This is sufficient to tend to raise the trolley one foot above the normal height of the wire.

In cold weather, however, on account of the various conditions affecting the operation of both the trolley and the overhead conductors the tension of the trolley springs is increased so that the trolley will rise to its maximum height.

The delays per month for the various parts of the equipment are given in Table I. The excessive number of delays due to the failure of the brake equipment were due mostly to the fact that no provision was made for "bleeding off" the brakes on a car if, for any reason, they had become "stuck." This has now been overcome by installing a bleed valve in the pressure chamber of the control valve. The air brake equipment was furnished by the Westinghouse Traction Brake Company, and is known as the A. M. C. E. equipment. Besides the well known automatic features of the Westinghouse air brake, this system is also controlled electrically, and is so designed that trains of from one car to any practical number are handled with ease. The electrical control of the brakes has given entire satisfaction. Under the heading of alternating-current equipment is included all high tension wiring, transformers and electrical car equipment, except the pantograph trolleys, which are shown separately. Control equipment includes all controlling apparatus and the 32 volt direct-current wiring. Pantograph delays are practically all due to breakages.

Reports of defects per month for various pieces of apparatus are given in Table II. These reports are turned in by trainmen, a printed car defect report as shown in Fig. 4, being used. This is made out in duplicate, one copy going to the shop and one to the despatcher. The despatcher holds the report and keeps the car out of service, if necessary, until it is OK'd by the shop foreman. During certain periods of the day all trains are composed of one car. This means that the failure of practically any piece of apparatus is a serious matter, and generally causes a delay, whereas if two or more cars were generally run per train the chance of delay from equipment failures would be greatly reduced. Also when single car trains are operated the trainmen are more apt to notice little peculiarities or irregularities in the operation of the cars. This is particularly noticeable with the brakes. On account of the high speed at which the cars are operated the service on the brakes is very severe and a lack of holding power is quickly noticed by the motormen. In this connection it was found that it was necessary to adjust the brake slack adjusters to the normal travel on the inspection pit, for if they were set up too close the angularity of the brake levers would affect the braking power sufficiently to inconvenience the motorman.

During the past year very little trouble has been experienced with the wiring and equipment. Transformers have given no trouble, and the reports shown under the heading of wiring were due to poor connec-

TABLE I—REPORT OF DELAYS PER MONTH DUE TO VARIOUS PARTS OF THE EQUIPMENT

Month	Brakes		A. C. Equipment		Control Equipment		Pantographs		Miscellaneous		Total Delays		Miles per Delay	Miles per Minute Delay	Cars out of Service	Total Miles
1913	No.	Min.	No.	Min.	No.	Min.	No.	Min.	No.	Min.	No.	Min.				
January	2	8	0	0	4	34	2	32	2	10	11	84	[illegible]	[illegible]	[illegible]	[illegible]
February	6	27	0	0	0	0	3	20	1	12	10	59	[illegible]	[illegible]	17	[illegible]
March	3	10	0	0	2	23	5	72	0	0	10	105	[illegible]	[illegible]	8	[illegible]
April	3	19	0	0	2	4	1	15	0	0	6	38	[illegible]	[illegible]	[illegible]	[illegible]
May	1	6	0	0	3	16	0	0	1	5	5	27	[illegible]	[illegible]	[illegible]	[illegible]
June	2	7	2	7	0	0	3	20	1	1	8	35	[illegible]	[illegible]	[illegible]	[illegible]
July	1	12	0	0	1	9	1	22	0	0	3	43	[illegible]	3 018	[illegible]	[illegible]
August	0	0	0	0	0	0	0	0	0	0	0	0	126 198	[illegible]	[illegible]	[illegible]
September	0	0	1	8	0	0	1	8	0	0	2	16	[illegible]	7 619	5	121 913
October	2	10	0	0	1	5	0	0	1	23	4	38	[illegible]	3 229	[illegible]	[illegible]
November	6	49	0	0	1	11	0	0	0	0	7	60	[illegible]	[illegible]	[illegible]	[illegible]
December	0	0	1	20	0	0	0	0	0	0	1	20	[illegible]	[illegible]	11	128 239
Totals	26	148	4	35	15	102	16	189	6	51	67	525	....		96	1 457 653
Av. per month	2.1	12.3	0.3	3	1.2	8.5	1.3	15.7	0.5	4.2	5.6	43.7	[illegible]	[illegible]	8	[illegible]

TABLE II—REPORT OF DEFECTS PER MONTH FOR VARIOUS PIECES OF APPARATUS—1913

1913	Compressors	Governors	Control Valves	Brakes leak off	Stuck Brakes	Electric Brakes	Feed Valves	Brake Valves	Brakes release slow	Poor Brakes	Emergency Valves	Whistles	Air Pipes	Angle Cocks & Hoses	Line Switches	A. C. Wiring	Transformers	Control Wiring	Current Relay
Jan.	1		4		1	4			7	3		1	1						
Feb.		3	[illegible]	3	8	4		9	7	6	1					1		1	2
March.	[illegible]	1	3		6		1	2	1	4		1			1				[illegible]
April.				2	3		[illegible]	2		2		1				1			
May.		1				[illegible]	[illegible]					1	1		1			1	1
June.				1	3	[illegible]	[illegible]	[illegible]	2	12				2	1	2		1	1
July.		1	8		4	8	1	2	2	3	1		1	1	1	[illegible]			1
August.			1		1				1	2	1		1		1				
Sept.			4		2	2		1	[illegible]	2	1	1		1		2		1	4
Oct.	1	1			1		1		3	2			1					1	
Nov.	4	3	1		3	2	3	1	7										3
Dec.	2	3			2	1	6		1	6		1							[illegible]
Totals.	11	13	26	[illegible]	34	[illegible]	19	25	28	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

1913	Line Relay	Overspeed Relay	Jumpers & Sockets	Switch Group	Switches	Lights	Battery Lights	Motor Leads	Pantographs	Batteries	Heaters	Motor [illegible]	Reversers	Motors	[illegible]	Flat Wheels	Hot Journals	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Totals
Jan.				3					15							9												[illegible]
Feb.					1			[illegible]	14		3	1				14												[illegible]
March.				1	1			[illegible]	10		1	1	1				1			1	2			5		1	1	[illegible]
April.			2		1									3														
May.			1		4					2				1		4								1				43
June.					1				17							3												74
July.				1	1				16	1			1															[illegible]
August.								1	[illegible]																			16
Sept.									6	2	1																1	70
Oct.		1		2	1				1		1														1	1		[illegible]
Nov.		1	1	1	3	1			14	1	7	2							1				1					84
Dec.				1	1				12	4		1												2				81
Totals.	[illegible]	1	1	12	17	1	2	[illegible]	[illegible]	20	23	8	10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	788

tions or poorly insulated leads. The batteries used for operating the control apparatus are beginning to show deterioration, due to the vibration and severe service. Experiments are now under way to relieve these conditions.

While a number of flat wheels are reported they were generally very slight and did not require turning. Gears and pinions have given very little trouble except in the case of twelve flexible or spring gears which were placed in service as an experiment. These were found to be weak at a number of points and the design was changed and the weak points eliminated. The new style gears are giving excellent service. It is safe to say that the spring gear will eventually be adapted as standard. Case hardened gear and pinion teeth have given remarkable results and are undoubtedly superior for this service.

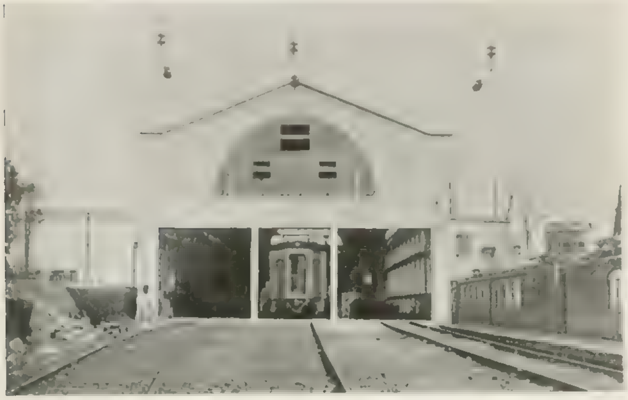


FIG. 6—REPAIR SHOP AND INSPECTION BARN

Located near the 180th street Bronx Park Station. The tracks to the extreme left are the main line tracks. The first track to the left in the shop is the one used for truck overhauling and repairs. The center shop track is the general car repair track while that to the right is the inspection track upon which the regular light inspection and oiling is done. The repair and inspection track each holds two cars. The extension shown to the right and rear of the main building is the general storehouse for the road. It will be noticed that exceptionally convenient arrangements have been provided for the care of the equipment and these have aided greatly in obtaining the excellent results as shown by the various tables. Platforms are provided at the sides of the cars for the aid of the car cleaners and one is also provided along the line of the roof for the convenience of the pantograph trolley inspectors. Car cleaning platforms are also provided between the tracks at the terminals. The live over-head wires are dead-ended one car length away from the shop.

A device for preventing the application of power to motors in the forward direction when there is air pressure in the brake cylinders has been applied to all cars and has fully met the results that were expected of it. It is assured now that the brakes are fully released when the power is applied to the motors, effecting a saving in brake shoe wear, power consumed and damage to the motors.

TABLE III—MOTOR AND TRANSFORMER TEMPERATURE MEASUREMENTS.

Car No.	Armature	Field	Commutator	Motor Shell	Transformer Core
[illegible]	59	57	84	39	47
[illegible]		60	84	40	46
[illegible]	[illegible]	[illegible]	90	39	51
103	70	50	85	36	50
11		60	80	36	50
11	[illegible]	[illegible]	72	44	51

An excessive number of hot boxes have occurred on the trailer trucks due to heavy braking and the use of a standard M. C. B. brass. The journal is forced out from under the brass when the brake is applied in emergency. On the motor truck, hot boxes are practically unknown, due to the use of a special brass with the sides extending well down on the journal and to the use of clasp brakes. The trailer truck has the simple brake rigging with one shoe per wheel. Hot motor bearings are also unknown.

Flashovers, or the jumping of current between brushholders, seldom occur, and are due either to high mica in the commutator or a severe fluctuation of voltage on the line. Flashovers do not have the serious damaging effect in a series single-phase motor that they do in direct-current motors, very little damage being done to an alternating-current motor.

During the early operation of the road considerable trouble was experienced through moisture entering the transformers and causing them to become grounded. This trouble was remedied by lowering the speed of the blower and by placing baffle plates in the air ducts to the transformer. Holes were drilled in the duct to drain off moisture that might collect before entering the transformer. The transformers were found to be running so cool that in damp weather the moisture would deposit on the coils. By reducing the speed of the blower and placing baffle plates in the air duct the amount of air sent through the transformer was greatly reduced, causing the desired rise in temperature and the elimination of all trouble due to moisture. No transformer trouble has occurred in the past year.

FIG. 7—INSIDE THE CAR BARN

Showing method of removing the motor truck from the car. The car body is raised with the aid of a 25 ton electric traveling crane and the stops as shown are let into place under the car. It is only necessary to raise the car body about 18 inches to remove the truck as it rests on a ball-bearing turntable and is easily revolved and removed from the side of the car. The stops as shown are built into concrete foundations and their safety and ease of operation as compared with the general method of using wooden horses or barrels will readily be appreciated.

Table III shows the temperatures of the principal parts affected by heat. The readings were taken on

the six cars after they had been in service for five hours. The temperature of the outside air was 24 degrees C.

It will be noticed that in the third case the figure for the commutator is high. This was due to that commutator having high mica. Commutators normally have the mica slotted 3/64 inch below the surface of the bars, and trouble is immediately experienced when it is allowed to run even with the surface. This causes the commutator to run at a higher temperature and the motor brushes break very rapidly. It was necessary to make all wiring connections, especially those carrying heavy currents, very secure and with full contact of the contact surfaces. Also the insulation on the high tension wiring connections had to be of high quality; otherwise the wiring and equipment needs no particular care.

The low voltage control system used for controlling the various pieces of apparatus has proven exceptionally efficient in service. Short-circuits or grounds are generally very troublesome on high voltage control systems but are practically unknown with the 32 volt control system as used on the "Westchester." Another advantage of the low voltage system is that all operating coils, magnets, etc., are operated in multiple without the necessity of resistances in the circuit, and a minimum complication of circuits is obtained.

The principal parts of the equipment changed per month are shown in Table IV. It will be noticed that an excessive number of battery lamps were used in the first few months. This was because they all reached the limit of their lives at about the same time, and also due to the fact that a 32 volt lamp was used originally, whereas the battery circuit when the battery is being charged by the motor-generator is considerably more than 32 volts. A 15 watt, 42 volt lamp has now been adapted as standard for use on the battery circuit, and the emergency lamps have been so connected that they light only when the line relay is open, as it is when the alternating-current power is off the car.

TABLE IV—EQUIPMENT PARTS CHANGED PER MONTH.

1913.	Motor generator auto-starter	Controller fingers	Switch group contact tips	Reverser fingers	Resistance grids	Motor carbons	Unit switches	Canopy switches	Canvas blower connections	Roller side bearings	Air brake hose	Line switch contacts	Motor brushholders	Heater coils	Pantograph [illegible]	[illegible] shoes	Journal bearings	Pantograph insulators	Battery lamps	Gauge lamps	[illegible] lamps	Motor [illegible] bearings	Motor [illegible]
Jan.		.....		6	6	285	2			1	.	1			130	[illegible]		2	[illegible]	24	[illegible]		
Feb.	1		.	. .	....	774	1	..	.	2			2		94	123	.	1	[illegible]	[illegible]	[illegible]		
March.		[illegible]	..	.		738	....	4	[illegible]	[illegible]			..	1	112	[illegible]			[illegible]	12	[illegible]		
April.	1	.		.	..	980			6		1	2			104	124			[illegible]	6	[illegible]		
May.		....	.			400			6	1	12		2		[illegible]	[illegible]			[illegible]	2			
June.	1	1	[illegible]	....		200			1	1	20	...	...		[illegible]	[illegible]			25	.	[illegible]		
July.	1	.	[illegible]	.	.....	100				[illegible]					[illegible]	[illegible]	[illegible]			9	[illegible]		
August.	....		60	.....		350			2	1	.				[illegible]	[illegible]				.	[illegible]		
Sept.			41	.....		475		.	.....	1					[illegible]	[illegible]		[illegible]			[illegible]		
Oct.	.		24	.		350	.			1	......			4	[illegible]	[illegible]	[illegible]	1	[illegible]	1	[illegible]	.	
Nov.	3	2	24			500			2	1		.		2	[illegible]	[illegible]			[illegible]		[illegible]		
Dec.	2	1	18		.	475		....		2	...		1	1	[illegible]	[illegible]			[illegible]		111	1	
Totals.	9	9	[illegible]	6	6	[illegible]	3	4	22	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1021	[illegible]	[illegible]	[illegible]	[illegible]	90	1102	[illegible]	

Controller fingers, which are quite an item of expense with other systems of control, are an insignificant expense. Switch group contact tips are worn out quite rapidly on account of the very heavy currents which are handled. An apparently excessive number of motor carbons are used, but this is partly due to the fact that each motor requires 24 brushes. The best success has been obtained with a soft graphite brush. The short-circuiting of the commutator bars by the brushes causes a small arcing which wears the brush quite rapidly, the average mileage from brushes being 21 667. While there are six brushholders per motor it will be noticed that very few have been replaced.

The remarkable service obtained from the motor bearings can be partly attributed to the effect of the alternating current. Since the torque and strains are not continuous, the oil is more thoroughly worked into the bearings. While great care is exercised in the shop in fitting bearings, less careful lubrication is required than with direct-current motors. The motor axle bearings show remarkable wearing qualities as, up to the present time, they show no appreciable wear. This is partly accounted for by the fact that extreme care was taken in having the axles finished to very accurate dimensions. The distance between wheel hubs is also machined accurately so that the motor has the proper amount of end play. The wheel and gear hub surfaces that act as bearing surfaces for the axle brass flanges were burnished as well as the axles, and gave excellent results. Good bearing surfaces were thus obtained without depending on the brass to polish the surface.

A great reduction in the quantity of material used has been effected by a careful study of the conditions and the elimination, so far as possible, of the causes of the trouble. From Table V it will be seen how the mileage obtainable from the various items has been increased. The mileage of brake shoes was increased by careful study of the operating conditions and the instruction of the motormen in the proper handling

of the brakes. The percentage of metal worn from the brake shoes before scrapping has gradually risen to 66 percent.

Table VI shows the lubrication cost per 1 000 car-miles for material; car cleaning cost per car per month for labor; kilowatt hours per car-mile and watthours per ton-mile; number of shopmen, and pantograph trolleys broken per month. Car cleaning is a difficult matter on account of the rust from the steel trolley wire and the trolley shoes. This deposits on the roof of the cars, and is worked down over the windows and sides of the cars. The roofs, which were originally painted a dark gray, were repainted with a color to match the rust deposit. Various methods of cleaning the car bodies were tried, but it was found that an oil cleaner gave the best results. The cars are swept each day and are thoroughly washed and disinfected twice a month.

TABLE V—MILEAGE OBTAINED FROM BRUSHES AND BRAKE AND PANTOGRAPH SHOES

1913	Brake Shoes		Pantograph Shoes		Motor Brushes	
	No. Used	Mls. per Shoe	No. Used	Mls. per Shoe	No. Used	Mls. per Brush
Jan.	219	[illegible]	130	840	285	18384
Feb.	123	9027	94	1049	774	6096
March	116	12205	112	1046	738	7624
April	124	11160	104	1109	980	5651
May	136	9957	96	1320	400	15214
June	90	12224	93	1557	200	30408
July	124	12558	89	1125	100	60884
Aug.	93	15052	66	1866	100	49688
Sept.	80	17011	50	2379	250	16308
Oct.	150	10054	46	2667	475	12384
Nov.	85	16917	66	1775	350	16068
Dec.	120	11644	75	1669	500	12017
Average	124	12075	85	1542	447	21667

TABLE VI—COSTS FOR LUBRICATION, CAR CLEANING, KW-HRS PER CAR-MILE, WATT-HRS. PER TON-MILE, ETC.

Lubrication Material c per 1000 Car miles	No. Shopmen	Total Eqpt. Dept. Payrolls	Car cleaning Labor Cost per Car per Mo.	Kw.-Hrs per Car-mile	Watt-Hrs. per Ton-Mile	Pantographs Broken
21	29	$2258.89	$6.48	5.60	93.3	4
20	29	2229.47	4.91	6.00	100.0	8
20	29	2687.07	6.42	5.42	88.3	9
25	21	2210.68	7.02	4.76	79.3	8
21	21	2267.47	7.02	4.55	75.9	6
20	22	2003.59	6.17	4.61	76.8	10
18	22	2139.41	6.69	4.65	77.5	8
19	22	2112.55	6.74	4.58	76.3	7
16	21	1980.08	6.63	4.48	74.5	4
22	20	2035.26	6.66	4.54	75.6	3
17	20	1849.96	6.74	4.91	81.6	4
23	20	2076.91	6.94	5.34	89.0	6
21	23	2161.86	6.51	4.94	82.3	6

The power necessary to operate the cars is a most important item, and the figures shown for kilowatt-hours consumption per car-mile speak very favorably for the single-phase system. The kilowatt and watthour readings include all power for the operation of the cars, such as heat and light, pumping up cars preparatory to placing them in service, and the power used in moving them over the road, or in switching around the yards or terminals. Each car is equipped with a watthour meter. This has been found to be a very satisfactory method of checking the current used by various motormen, and the constant studying and checking of the wattmeter readings has effected a great saving in the amount of power used.

Tables VII and VIII show the costs for labor and material for the maintenance of the equipment for the year 1913. Repair costs cover all charges for replacements and repairs. Inspection costs cover the general car barn inspection work. Car cleaning and lubricating materials, and incandescent lamps, are not shown in Tables VII and VIII, they having been shown elsewhere, as they are not properly chargeable directly to maintenance of equipment.

TABLE VII—MAINTENANCE COSTS IN DOLLARS—REPAIRS

1913	A C Eqpt.	Motors	Cont Eqpt	Car Body	Trucks Wheels Axles	Gears and Pinions	Pantos	Air Brakes	Brake Shoes	Misc. Shop Exp. and Supervision	Term Inspectors	Oilers	Totals	Cents cost per car mile
January	234.20	1557.06	282.92	116.05	87.87	40.94	122.31	168.71	123.82	659.37			3393.34	3.01
February	209.21	169.49	319.84	162.66	117.87	85.82	110.05	111.53	46.60	675.74			2008.71	2.00
March	335.41	270.38	215.73	418.54	108.81	23.81	216.02	80.18	170.75	1312.16			3147.79	2.61
April	410.81	230.98	307.72	203.94	74.82	181.83	119.48	75.45	62.91	699.54			2366.98	2.02
May	45.62	102.95	47.55	57.70	75.03	6.00	159.03	101.36	221.51	835.65			1652.40	1.27
June	86.61	129.37	77.21	107.90	180.65	39.07	219.00	97.47	140.25	605.64			1683.17	1.30
July	169.44	94.22	106.46	115.39	277.91	6.00	157.33	66.31	228.12	421.54			1632.78	1.25
August	140.26	85.20	95.83	161.59	282.26	29.05	160.83	74.44	162.41	436.03			1627.90	1.28
September	126.08	105.27	71.85	276.48	193.29	...	119.43	108.85	164.81	439.37			1604.88	1.31
October	94.02	136.65	101.77	139.08	165.57	13.25	95.37	82.83	152.14	366.72			1346.90	1.07
November	79.25	68.66	97.36	231.42	117.55	7.25	68.69	77.75	137.72	465.18			1353.73	1.12
December	150.01	105.03	191.40	213.55	112.27	28.99	169.65	60.91	187.78	300.00			1509.62	1.17
Average	172.06	254.61	159.64	183.95	149.04	38.50	143.10	92.05	149.06	601.49			1944.02	1.62

TABLE VIII—MAINTENANCE IN DOLLARS—INSPECTION

January	50.25	52.98	83.46	40.50	37.30	16.15	31.15	29.75	15.25	150.00	300.00	58.73	865.52	0.77
February	48.50	47.25	75.75	[illegible]	37.50	15.00	30.50	32.60	22.00	135.50	241.50	49.30	770.95	0.76
March	52.00	55.50	78.75	38.90	40.25	12.00	32.50	34.75	24.23	125.00	337.00	45.00	875.88	0.73
April	60.82	83.29	40.56	[illegible]	73.12	11.75	55.23	57.35	60.52	138.99	357.00	65.00	1017.25	0.86
May	67.81	95.06	40.00	50.00	76.41	44.42	75.00	41.41	28.86	156.10	372.00	48.50	1085.62	0.83
June	31.16	30.72	33.28	16.83	58.90	17.58	26.53	26.17	26.85	77.90	358.00	73.58	790.56	0.61
July	60.73	26.31	47.00	20.00	73.93	2.85	50.59	58.96	38.60	105.68	363.00	90.57	936.25	0.72
August	75.41	19.35	42.38	23.05	83.94	29.05	39.00	64.13	32.56	120.70	376.65	61.49	967.71	0.76
September	35.25	26.24	19.64	[illegible]	44.01	3.00	34.00	[illegible]	32.11	110.90	363.90	74.54	863.73	0.70
October	30.30	61.51	41.52	42.01	86.12	12.28	29.00	30.37	25.11	113.68	372.00	96.96	940.86	0.74
November	36.19	48.00	45.30	30.04	63.32	7.23	36.74	53.00	26.00	111.40	360.00	88.42	905.69	0.75
December	53.17	52.97	83.46	[illegible]	37.29	16.08	31.00	29.98	23.92	151.75	366.00	57.25	943.40	0.73
Average	[illegible]	49.93	52.59	[illegible]	59.34	15.62	40.10	[illegible]	[illegible]	124.65	347.25	67.45	913.62	0.74

Note—Car cleaning and lubricating materials and incandescent lamps not in the above.

The cars up to Dec. 31, 1913, made a total of 2 082 726 miles, the greatest mileage made by any car being 86 109 and the least 23 004; the average mileage being 69 424.

Lightning Arresters for the Protection of Electric Railway Equipment

Q. A. Brackett

THE PROTECTION of electric railway equipment from lightning presents the problem of lightning protection in its broadest form. Not only do the power houses and sub-stations require protection in the same way and of the same sort as other stationary and localized installations of apparatus, but a large part of a railway company's equipment is continually in motion over more or less exposed lines as if actually in search of lightning trouble, and this equipment must carry its protection with it. These car equipments present a problem of protection that is peculiar to electric railway practice, for while both continuity of service and value of the motors call for first-class protection of each car, the large number of separate cars to be protected makes a very low price arrester a prime requisite.

In railway practice there are three classes of arresters, namely, those for cars, lines and station. The same type may be used for all of these, but in general there are differences in the requirements of these classes of service that have an important bearing on the choice of the arrester.

Car Arresters should be portable, rugged mechanically to provide against continual vibration, small in size, capable of being located in any place or position that is available and should require the minimum of inspection and attention, because the great number of cars equipped would render individual care and attention a most burdensome and expensive procedure. Car arresters should have high protective ability where line arresters are not used, and as the latter are not always used to an equal extent, if at all, on all the lines of a company, it is highly advisable that car arresters should always be of the highest effectiveness compatible with the other requirements and of reasonable cost.

Line Arresters need not be as effective as car arresters, as it is assumed that there will be several used per mile and that the cars will also have arresters. They must, however, give fairly good protection and be weather-proof, suitable for pole mounting, cost little, because of the large number used, and require the least possible attention and repair, because of their wide distribution over a district and the consequent difficulty and expense of visiting each one periodically for purposes of inspection.

Station Arresters should be the most effective obtainable, as they protect the heart of the whole system and the cost and importance of the apparatus protected warrants the use of an arrester many times more expensive than those used elsewhere on the system. As they are located where attention is always available and as they are always few in number, types may be used which require considerable attention, if by so doing greater freedom from trouble can be obtained.

As the great majority of electric railways are operated by direct current, none of the arresters of the non-arcing metal type, common on alternating-current circuits, can be used. Of those that are customary, there are two general classes, namely, those that allow a direct-current arc to follow the discharge and then break the arc by some means, such as a circuit breaker or magnetic blow-out, and those that allow no power arc to follow, and handle only the transient energy. Other things being equal, the closer an arrester approaches the latter class, the better it will be. The arrester will not burn itself at each discharge and it will not cause secondary surges on the line by the sudden breaking of a power arc.

CIRCUIT BREAKER TYPE

Various types of arresters for car and line protection have been developed from time to time. Of the class that allows a power arc to follow a discharge, the most common are the circuit breaker and the magnetic blow-out types. The first of these consists usually of a resistance rod in series with a spark gap and a pair of circuit breaker contacts that are caused to open and break the power arc following a discharge, through the action of a magnet coil connected across all or a part of the series resistance. In the usual construction, the circuit breaker takes the form of a plunger type solenoid, the contracts being normally held together by gravity and the plunger operating in an insulating tube. When a discharge takes place the coil is energized by the drop across the resistance and lifts the plunger, thus drawing out the arc until it breaks. The plunger then falls back against the lower contact again.

While this arrester lends itself well to pole mounting, it is less suitale for use on cars because of the necessity of mounting it in a vertical position, since the circuit breaker is reset by gravity. The continual vibration of the car likewise tends to develop friction and wear, which in time makes the operation of the moving parts of the circuit breaker uncertain, while the continual bouncing up and down of the plunger renders the total spark gap of the arrester considerably greater than normal a large percentage of the time, and thus greatly reduces its protective effectiveness. This is still further reduced by the use of a rather high series resistance necessary to prevent discharges from so burning the circuit breaker contacts that the plunger might stick in its containing tube, as has been known to happen. A serious objection also,

to this type of arrester is the fact that, after each discharge, there is a period during which the plunger is up and the arrester practically disconnected from the line and affording no protection to the apparatus. This is a particularly serious objection, because of the fact that multiple lightning discharges, following in quick succession, are of most frequent occurrence and may cause serious injury to the apparatus, unless the arrester is always in circuit ready to take discharges at all times—no matter how rapidly they may come.

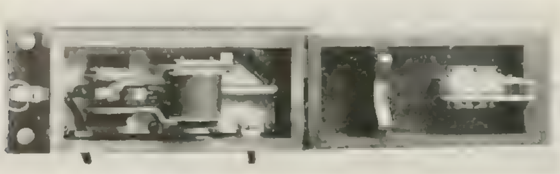


FIG. 1—MAGNETIC BLOW-OUT TYPE OF LIGHTNING ARRESTER

THE MAGNETIC BLOW-OUT TYPE

The magnetic blow-out arrester operates on an old and well-known principle much used in connection with direct-current switches, etc. It usually consists of a spark gap and a resistance rod in series, the spark gap being located in the field of a powerful electromagnet which is energized by the drop in all or a part of the resistance rod when the power current flows through it after a discharge. The effect of the magnet is to drive the power arc quickly and violently out of the spark gap and thus put it out, Fig. 1 shows a successful arrester of this type so designed that when the box is opened the circuit is broken, thus making it possible to adjust the gap or replace the resistance rod without danger. This type of arrester, like any other using a series resistance, is limited as to freedom of discharge if the resistance is made high and stands in danger of burning itself up if the resistance is made too low, or the arc hangs on, due to an ineffective blow-out. Where an electromagnet is used there is always the danger of a lead breaking off or coming loose, due to the continual vibration of the car and thus eliminating the blow-out effect and allowing the arrester to be destroyed, whereas, where a permanent magnet is used there is danger of the blow-out effect being too weak or the magnet becoming demagnetized and weakened by successive heavy discharges.

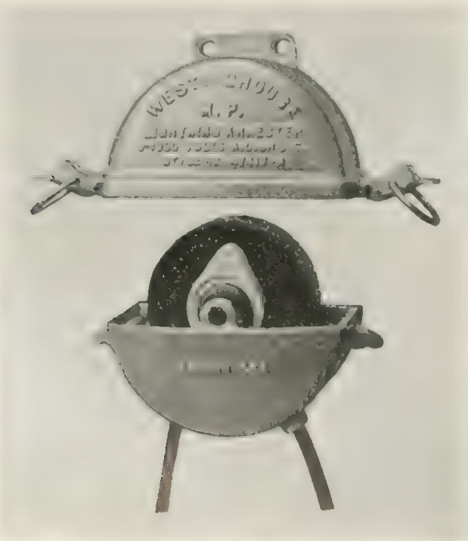


FIG. 2—MULTIPATH ARRESTER, SHOWING CARBORUNDUM DISC AND CASE

THE MULTIPATH ARRESTER

Of that class of arresters that releases only the transient energy of a surge and does not allow the formation of a dynamic power arc, one of the oldest and best, as well as the cheapest, is the so-called "Multipath type." This arrester, which is shown in Fig. 2, and tens of thousands which have been used during the last decade, consists of a specially prepared carborundum block in series with a very small spark gap—the whole mounted rigidly in a weather-proof cast iron case. For ordinary voltages, this block is in effect a very high resistance, almost an insulator in fact, yet if the voltage rises above a certain critical value it breaks down into a multitude of minute spark gaps.

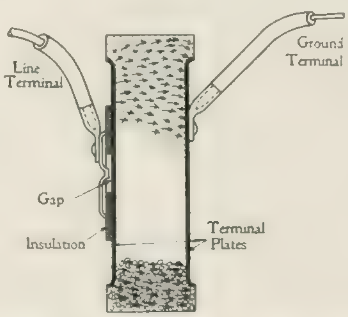


FIG. 3—SECTION OF CARBORUNDUM DISC AND INSIDE DETAILS OF ARRESTER SHOWN IN FIG. 2

The discharge spreads throughout the block, jumping from particle to particle, as shown in Fig. 3. As soon as the high voltage has passed the block resumes its insulating characteristics, the discharge being practically instantaneously quenched by the multitude of minute spark gaps, among which it is divided and by the cooling effect of the great mass of the block. The action of the block greatly resembles that of the aluminum film in the electrolytic arrester, except that its current discharge at normal voltage is much less, due to its much lower electro-static capacity.

This type of arrester is extremely simple, compact and rugged and particularly adapted to stand the continual jarring of street car service—being much superior in that respect to any type having moving parts. Unlike the latter type, also, it can be mounted in any position or place that is most convenient and it takes up very little room. Since no heavy power current follows a discharge, the series spark gap, used to keep the block normally insulated and so free from deterioration, can be made very small, as burning or fusing the gap need not be feared. The gap used is only slightly greater than one sixty-fourth of an inch, which is smaller than can be used with any arrester that permits power current to flow, and this small gap causes it to discharge and begin to give protection on a rise in voltage before the other type of arrester would have

come into play. Not only does it offer protection sooner, but it likewise provides great freedom of discharge for over-voltages, thus showing that during a discharge the carborundum block ceases to be a resistance and becomes, instead, a collection of series and parallel spark gaps without a resistance.

The usual way to test the freedom of discharge of an arrester is to measure the so-called "equivalent spark gap." This consists of connecting in parallel with the arrester an adjustable spark gap with no series resistance, and then impressing on the arrester discharges of artificial lightning from a large condenser charged up to a high voltage. The shunting gap is then reduced until it just robs the arrester of the discharge. This gap separation is then called the equivalent spark gap of the arrester. As its value in inches is dependent on various things, such as the steepness of the wave front of the condenser discharge

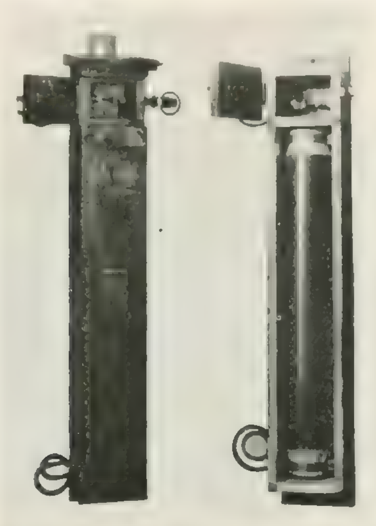


FIG. 4—CONDENSER TYPE ARRESTER FOR CAR MOUNTING

and the shape of the electrodes of the shunting spark gap, it is necessary if comparative results are desired, to test all the arresters on the same circuit and under the same conditions. In such a test made recently the average equivalent spark gap of a large number of multipath arresters was found to be 0.102 of an inch, while that of one of the common circuit-breaker type arresters for the same service was 0.213 of an inch, and that of a standard magnetic blow-out arrester was 0.252 of an inch. The voltages at which they began to discharge were 1 750, 2 830 and 3 050. This shows that the multipath arrester not only discharges at a lower voltage, but provides *over twice as great freedom of discharge.* Two multipath arresters in parallel had an equivalent gap of only 0.070 of an inch, although their combined cost is less than that of most other types of arresters, thus showing the possibilities of using two or more multipath arresters on one car where conditions are especially severe and yet the cost of arresters must be kept low.

This shows that the multipath arrester not only is free from trouble itself, since the absence of any power arc eliminates any danger of its burning itself up, but that it also provides the most complete protection against trouble to the apparatus which it protects, which accounts for its continued success during the past ten years.

The only criticism usually brought against the multipath arrester is that, since the spark gap is invisible and it handles discharges so quietly and without distress, those who have been used to arresters which go off with a loud report and seem to nearly tear themselves to pieces, find it difficult to believe that it is really working. Some of its really good points are, therefore, sometimes against it psychologically, but that is not a fatal fault in an arrester.

CONDENSER TYPE ARRESTER

Belonging to the same class of arresters that do not allow the flow of power current and perhaps the most perfect example of that class, are the new condenser type arresters recently developed. This type is also a perfect example of an arrester that can be mounted in any position on top of or under a car, or on a pole and which will never require any attention after it is once installed. This arrester, which is illustrated in Fig. 4, consists of a tubular rolled-up condenser, shunted by a high resistance—both in series with a small spark gap. These parts are enclosed in an oblong box, and the condenser and resistance are imbedded in gum, so that they are entirely weather-proof. The spark gap is in a separate compartment at one end of the box, and a hinged cover for this compartment affords easy inspection of the gap. For high frequency surges—such as the majority of lightning disturbances are—the condenser acts almost as a dead short-circuit across the apparatus to be protected, yet it allows no direct current to flow. It thus automatically selects out and shunts by the apparatus the high frequencies against which it is intended to protect, without providing any path whatever for the ordinary direct current. This comes quite close to the ideal for a lightning arrester, especially as, on railway circuits, high frequency troubles are the most serious of all.

For traveling direct-current waves, on the other hand, the condenser is equivalent to many miles of line which the surge must charge before it can hit the apparatus being protected. For such direct-current waves the action of the condenser is like that of a wide and deep trench dug in the path of an advancing wave of water, which the latter must fill up before it can advance farther, and which, in any case, greatly reduces the steepness of the wave front. The resistance shunting the condenser is equivalent to a drain so located as to let the water run out of the trench again, not so fast as it came in, perhaps, but amply fast enough to be ready for the next wave.

The condensers used in the 750 volt car arresters are equal in capacity to over forty miles of trolley line, while those for line use are equal to over ten miles of line, which, with five arresters per mile, as recommended, gives fifty miles of line protection for each one mile of actual line. The spark gap used in

series serves to keep the condenser normally insulated from the line so that the resistance can keep it always discharged and with its full storage capacity available. It also allows of the insertion of tell-tale papers when it is desired to obtain records of discharges and provides the "visible spark gap" so much desired by some users. As the condenser never allows the passage of any direct power arc across the gap the burning of the latter is so slight that the setting can be made much

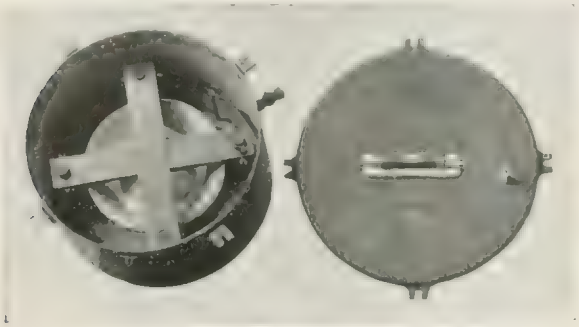


FIG. 5—ELECTROLYTIC LIGHTNING ARRESTER
Showing internal arrangement.

closer than with other types of arresters. It is ordinarily set to discharge at about 1 500 volts, which is less than half the insulation test of street railway apparatus, and so insures its operation before any dangerous rise of voltage can occur. The spark gap can, however, if preferred, be entirely short-circuited without harm. This will make the arrester somewhat quicker to render relief, but slightly less effective as a whole.

This arrester has no rival as a protective device for street cars, except the electrolytic arrester. In protective value it is equal to the latter in the small sizes in which the latter has been used on cars, while in freedom from attention, repair and general bother it is in a class by itself. Neither hot nor freezing weather will injure its effectiveness, chemical deterioration will not render renewals necessary every few months, and the absence of liquid will allow of its being located in any position on top of or underneath

FIG. 6—[illegible] INSTALLATION OF MULTIPATH ARRESTERS FOR [illegible] PROTECTION

the car. Where many cars are equipped this freedom from attention will be of great importance, as will also the freedom from the danger of a short-circuit on the line liable to occur with the electrolytic arrester, due to the dissolution of the film where a car has been standing idle a few days with its trolley off, as for instance, in a repair shop, and is then put back in service.

The condenser type car arrester is also suitable for station protection, and for that purpose is superior to any type except the electrolytic arrester of large size. The objectionable features that are so serious against the use of the electrolytic arrester and cars, such as care, attention, renewals, cost, etc., do not apply, however, to station service where attendance is available and the apparatus to be protected represents a large investment. For this service a large size electrolytic arrester, using the same size aluminum trays as are used in the large electrolytic arresters for alternating power circuits, is to be preferred. This arrester has much greater protective power and thermal capacity than any small jar type electrolytic arrester and is not limited as to station capacity as the latter is. For this arrester a new electrolytic has recently been developed which is proven by tests to be superior to any other for this service. It re-forms the film and stops the flow of power current after a discharge more quickly than any other electrolytic hitherto developed, and it is much less affected by heat, as no

FIG. 7—AN UNUSUAL INSTALLATION OF THE MULTIPATH TYPE ARRESTER FOR STATION PROTECTION, WHICH IS GENERALLY TAKEN CARE OF BY ELECTROLYTIC ARRESTERS

trouble is experienced with it at any temperature which is likely to be met in practice; in fact, it operates equally well when boiling. It does not dissolve off the film as rapidly and it is so stable that there is no need whatever for balancing resistances such as have been considered necessary with the small jar type electrolytic arresters in order to keep the voltages equal across the different jars in series.

To Summarize what has been said above, the power house and sub-stations of a street railway company should be protected by large capacity electrolytic arresters, such as shown in Fig. 5, since their cost and maintenance is warranted by the value of continuity of service and the apparatus to be protected, and their protective power is somewhat greater than that of any other type. A large condenser type arrester, however, is but little less effective for this service, and will require less attention. In a few cases, such as shown in Fig. 7, the multipath type of arrester has been used for this service but such installations are rare.

The pole line should be protected by five equally spaced arresters per mile, of at least moderate effect-

iveness, and the arrester used should be weather-proof, suitable for pole mounting and should require the very minimum of repair and inspection. The multipath and and the pole-type condenser arresters fill these requirements better than the circuit breaker and magnetic blow-out type, not only because of their greater protective effectiveness, but, especially for line protection, because of their almost absolute freedom from all need of repair and inspection. An installation of multipath arresters for line protection is shown in Fig. 6.

For the cars themselves, the arrester used must, above all, afford a very high degree of protection, yet the first cost and maintenance expense and trouble must be a minimum and the ability to mount the arrester in any convenient position is a most desirable characteristic. The multipath type of arrester possesses all these features in a marked degree and is superior to either the circuit breaker or magnetic blowout types in all respects for car service. Still greater protection can be obtained at a cost no greater than that for one arrester of other types by the use of two multipath arresters in parallel. Where the lightning conditions are very severe and the very highest degree of protection is required—irrespective of cost—the condenser type of arrester will be found to have ample protective power and to be far superior to the electrolytic arrester for car service, due to its entire freedom from any need of further attention and trouble after it has been once installed.

Charging Resistances for Electrolytic Lightning Arresters

G. C. Dill

CHARGING RESISTANCES for use in electrolytic lightning arresters have been in existence for quite a number of years, but their application has been very special and their existence scarcely known to users of electrical apparatus except in these special cases.

When the electrolytic lightning arrester was developed it was found that when alternating current was passing through a cell or stack of trays of an arrester, ripples or surges were set up in the charging current.* This was due to the electrostatic capacity of the arrester. The primary reason for the use of charging resistance with an electrolytic lightning arresters is to dampen out these ripples or surges which under certain conditions are objectionable, and might lead to injury of the apparatus.

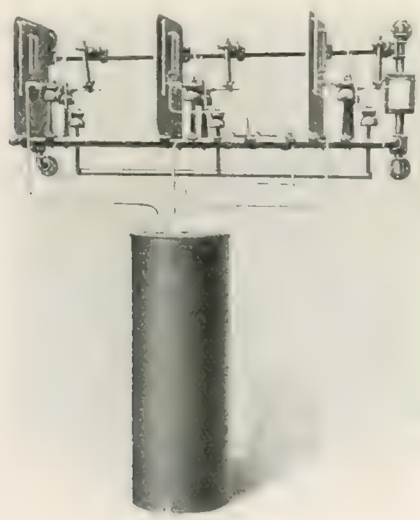
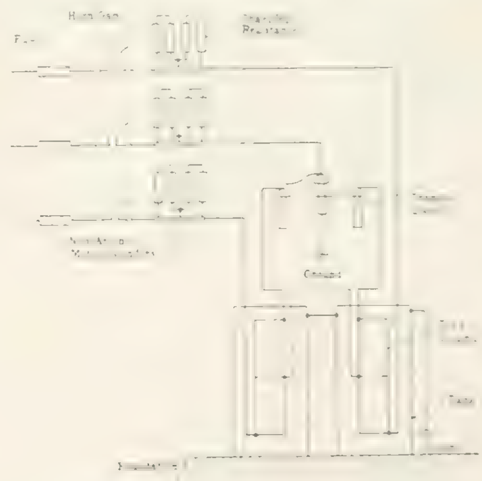


FIG. 1—A TYPICAL INSTALLATION

Showing a low voltage electrolytic lighting arrester together with the location and mounting of the charging resistance.

Under most ordinary conditions the surges or ripples set up by the charging of an electrolytic lightning arrester are harmless; first, because most electrolytic arresters are used in transmission lines which have transformers interposed between the arrester and the more vulnerable apparatus in the station or substation and usually transformers have ample insulation on the end turns to withstand the comparatively low voltages of these surges; and second, because most aerial transmission lines have their line constants (resistance, inductance and capacity) such that there is very little or no tendency towards resonance, which might possibly be of a frequency near the natural frequency of the surges set up by the charging of the arrester. Cable systems on the other hand have much less inductance and very much higher electrostatic capacity than aerial lines; that is, the condition of resonance is more nearly approached. The effect of this is to cause a higher charging current and to increase the voltage



2—DIAGRAM OF CONNECTIONS

Of an electrolytic arrester for 10 000 to 14 500 volt, three-phase ungrounded neutral service.

*See the JOURNAL, volume 7, page 619, Fig. 3.

of the surges or ripples and it was this condition that first lead to the use of charging resistances.

Modern transformers usually have their end turns well insulated and the ripples or surges set up

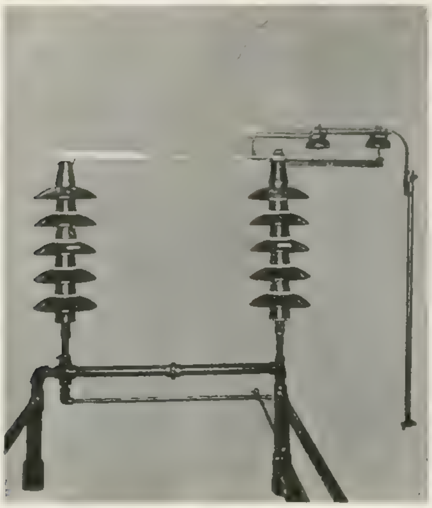


Fig. 3—One phase of a 110 000 volt three-phase arrester
For ungrounded neutral service, showing horn gap and resistance cylinders.

have but little or no effect upon them. Generators and motors, however, when compared with transformers, have comparatively weak insulation, and when generators or motors are connected to a circuit without the use of transformers and are protected by electrolytic arresters without charging resistance, the charging of the arresters may in some cases cause punctures of the insulation of the windings.

As a general rule, charging resistances should be used with electrolytic lightning arresters when the latter are used for the protection of :—

a—Cable systems.
b—Motors and generators which are connected directly to a transmission line without the use of intervening transformers.
c—Transformers which have weak insulation on the end turns.

The lower voltage arresters equipped with charging resistance, have this resistance as an integral part

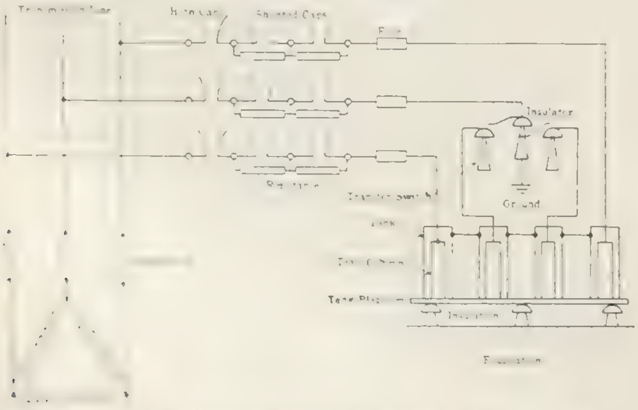


Fig. 4—Diagram showing complete circuit of arrester in Fig. 3

of the arrester, while on arresters for higher voltages the manufacturer furnishes it as an attachment which can be placed on a standard arrester. A low voltage arrester equipped with a charging resistance is shown in Fig. 1 and the circuit of a 10 000 to 14 500 volt, three-phase, ungrounded neutral arrester with charging resistance is shown in Fig. 2. In this arrester the charging resistance consists of a group of non-arcing metal cylinders shunted by suitable resistances which are of the composition stick type. A charging resistance and horn gap for one phase of a 110 000 volt lightning arrester is shown in Fig. 3 and the complete circuit of a high voltage, three-phase, ungrounded neutral arrester equipped with charging resistance is shown in Fig. 4. The charging resistance, such as shown in Fig. 3, consists of two auxiliary horn gaps, each of which is shunted by a large rugged composition stick resistance. This type of charging resistance is suitable for outdoor mounting and three such resistances are required with any three-phase arrester.

The action of the charging resistance is the same with the shunted non-arcing metal cylinder type as with the shunted horn type. When the arrester is charged, the main horn gaps are bridged and the gaps between the non-arcing metal cylinders, or between

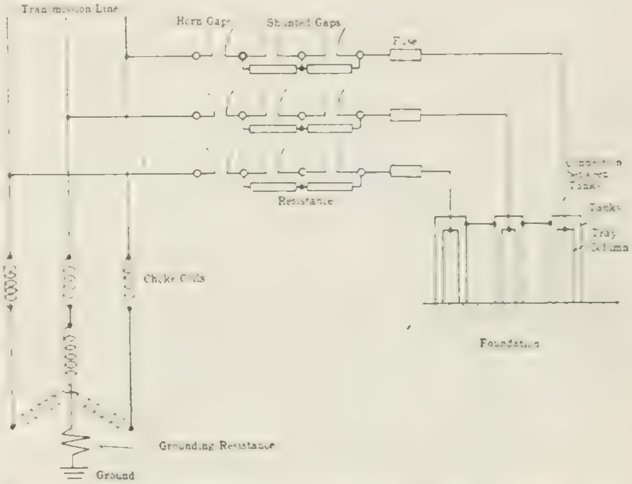


Fig. 5—Diagram showing connection for arrester and charging resistance on a three-phase grounded neutral system

the auxiliary horns are sufficiently great so that the potential at the times of the charging operation will not break them down. Consequently, the charging current is compelled to flow through the resistance, so that the ripples or surges set up by the electrolytic cell are damped out.

If, however, a lightning discharge should occur, it would flow to ground through the resistance until such time as the current flowing through the resistance should become so great as to produce a voltage across the auxiliary gaps sufficient to break them down. Then the charge would shunt the resistance, and have a free path to ground until such time as the flow of current to ground should no longer continue great enough to maintain the arc across the gaps, when the flow of current would again be through the resistance.

From the above it will be seen that the function and general effect of a charging resistance is to produce steadier conditions and maintain the stability of the electrolytic lightning arrester circuit.

An Important Development in Steam Railroad Electrification

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THE night of January 24, 1914, was a notable one in the history of heavy steam electrification in America. On this night the New York, New Haven & Hartford Railroad Company, operating the largest electrified system in the world, made important changes in its methods of supplying energy to its trains. The consequences of these changes are so far reaching that it has been felt to be both desirable and necessary to give to all interested a statement of these changes, the reasons which made them desirable, the expected benefits to be derived therefrom and the extent to which the expectations of those responsible for these changes have been realized.

FIG. 1 MAP OF NEW ENGLAND STATES SHOWING ELECTRIFIED PORTION OF NEW YORK, NEW HAVEN AND HARTFORD RAILWAY SYSTEM

For the benefit of any who are not familiar with the general features of the N. Y., N. H. & H. electrification system, a brief outline will be given of its history and status. By reference to Fig. 1 it will be seen that it forms a part of the main trunk line between the cities of New York and Boston, and is an important part of the total New England railroad system. This fact had to be given full weight by the engineers who, eight or nine years ago, were responsible for the decision as to the system to be adopted for this electrification. Regard for its location as a part of the main artery of a big system and a careful consideration of the nature of the traffic, as well as the long distances and large range of operation which ultimately would have to be negotiated, led to the adoption of the single-phase system as offering the most flexible and economical solution of the many problems involved.

Engineers the world over are now in substantial agreement as to the salient facts with regard to the comparative merits and limitations of the various systems of electrification. It has been realized that into every electrification problem enters a large number of considerations; the density of the traffic; the distances involved, both at the start and in the future; interchange of freight and passenger traffic between adjacent roads; overall operating efficiency; the need or otherwise for flexibility in speed control; adaptability to different classes of service; the cost of investment; cost of operation and maintenance, etc., etc.; or in the broadest sense—overall commercial efficiency inclusive of all present and future considerations.

As bearing on the history of the New Haven electrification, it may be well to state the general agreements which have gradually established themselves. The direct-current system has been found well suited to high density passenger traffic where the range of

transmission is small; with larger distances, however, the substation and feeder costs become prohibitive. The single-phase system possesses advantages where greater distances are involved and where a general electrification is contemplated, owing to its lower first cost, lower operating cost, greater flexibility as regards speed control, high transmission efficiency and ready adaptability to all classes of services under a single wire. There are many problems to which the use of direct current would be the correct solution, but in general wherever it has been expected that the initial electrified zone would in the future be extended to cover large distances and a wide variety of requirements inclusive of passenger, freight, switching and miscellaneous services, the engineers have decided to use the single-phase system. This agreement, reached almost simultaneously in America and in Europe, is a splendid tribute to the far sightedness and courage of those engineers who years ago had the courage to recommend what was then a comparatively new system. It represents, however, a perfectly natural growth and is due to a clearer and more general appreciation of the fundamental principles involved, as well as the physical demonstration of flexibility and efficiency which has since been given, not alone in America, but in England, Switzerland, France, Germany, Denmark and other countries. European engineers were quick to grasp the importance of the new developments and their practical bearing upon future work. Perhaps the best instance of this is to be seen in Switzerland, or on the London, Brighton & South Coast Railway of England, where soon there will be approximately 250 miles of railway, some of which traverses the most congested territory in the world—all electrified on the single-phase system.

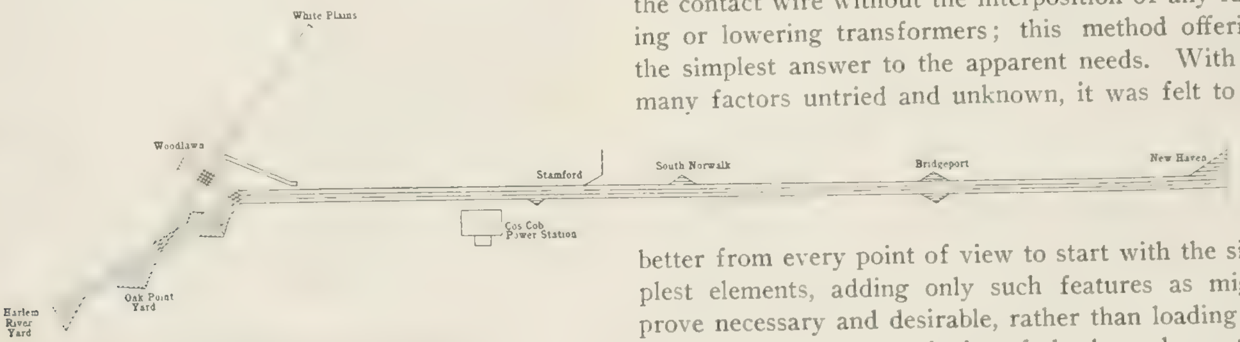


FIG. 2—SCHEMATIC DIAGRAM OF TRACKS

American development, outside of the New Haven system, for a time moved more slowly, halted no doubt by the conservatism which waited patiently for results to be demonstrated. The recent decision of the Pennsylvania and the Norfolk & Western Railroads to use the single-phase system for their general electrification work marks the end of this halting period and brings American engineering into line with the rest of the engineering world.

The Pennsylvania Railroad—the premier railroad of the world—has a reputation for thoroughness and for sound, conservative business policy. The whole fabric of its business and organization has been reared upon these characteristics and upon the proven ability and clear-sightedness of its officials. Their decision, therefore, made after an extended experience with direct current, is the strongest endorsement which could have been given to the single-phase system. This decision is the more significant when it is remembered that the initial single-phase electrification at Philadelphia is one involving high density passenger suburban service handled by motor car multiple-unit trains.

Several years ago, at the time the electrification of the New Haven system was first contemplated, experience with important electrified steam railroads operating at more than a few thousand volts, was very meagre. The New Haven engineers decided upon 11 000 volts as the working pressure. This was a radical departure, and necessarily introduced many new problems and difficulties. The need, however, of a high voltage alternating current in an overhead wire was imperative, and the difficulties had to be met and vanquished. It was further decided to supply the 11 000 volts from the generator terminals directly to the contact wire without the interposition of any raising or lowering transformers; this method offering the simplest answer to the apparent needs. With so many factors untried and unknown, it was felt to be better from every point of view to start with the simplest elements, adding only such features as might prove necessary and desirable, rather than loading up at the start with a complexity of checks and counter-checks based solely upon undefined apprehensions and which later might prove to be only expensive frills. The three separate links in the electrified chain, viz., power house, overhead line and rolling stock, had been tried out separately. They had never been tried out on a large scale in combination. The New Haven engineers undertook to combine them and produce a new result. The results of their work are now matters of history, and have been so fully covered in Mr. W. S. Murray's contributions to the proceedings of the A. I. E. E., as well as in the technical press, that they will not be but touched on herein. Suffice it to say, that to each sore spot or detail weakness as it developed was applied the healing salve of common sense, backed by the engineering experience of many trained minds working in concert. The result was inevitable; the possibilities of the new system were fully developed and realized; and, with equal frankness, be it said that the limitations of the arrangement as originally conceived were equally established. It was anticipated that experience would undoubtedly develop these limitations, since progress is made by step-by-step methods, and never all at once. After four years then, two small difficulties remained, awaiting attention.

One was a need for more positive correction of electro-magnetic disturbances in neighboring telegraph and telephone circuits—a large number of which parallel the railroad tracks. Corrective measures had been applied at a very early stage, and in general had proved quite successful. The growing volume of business, however, necessitating larger and larger currents, considerably increased these effects, especially when grounds or short-circuits occurred. It would have been feasible to continue to add to the number of neutralizing transformers and other corrective apparatus, and so retain the *status quo*, but this did not entirely satisfy those responsible for a decision. It was felt to be better to try and remove the cause, rather than correct the resulting effect.

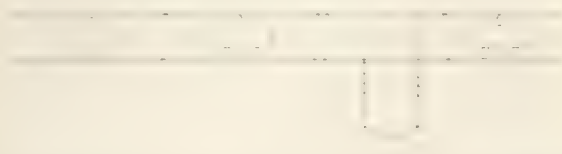


FIG. 3—OUTLINE DIAGRAM OF ORIGINAL SYSTEM OF ELECTRIFICATION

The other need was related to the transmission voltage. As already stated, the pressure at the generator terminals and on the overhead wires was 11 000 volts. Generators could not then, and cannot now, be economically built for much higher voltages. Meanwhile, ideas of what constituted a high transmission voltage were rapidly changing, and although 11 000 volts had at one time seemed so radical, yet it was now no longer so. Looking into the future it was anticipated that needs would arise for much higher voltages than were originally conceived. The direct connection between generator and line limited this possibility and should be modified accordingly. The rapid growth of the business, accompanied by a large extension to the range of operation which took place when the Harlem River branch and freight yards were added, emphasized this, and it was still further emphasized by the decision to extend electrical operation to New Haven—a distance of 45 miles. The difficulties, however, in the way of raising the transmission voltage were considerable, since it meant that the insulation on approximately 350 of the total 572 miles of overhead contact wire, Fig. 2, with its attendant rolling stock and other apparatus apparently would need to be replaced.

After much searching a solution was most happily found, which, it appeared, would simultaneously solve in a simple manner both problems, viz., inductive disturbances and the need for obtaining a higher transmission voltage without increasing the potential stress to ground. By referring to Figs. 3 and 4, in which are shown schematic outlines of the original electrification system, and of the new one recently inaugurated, it will be seen that under the old system all of the current flowing either in the overhead wire or in the rails or ground return, was in the same direction for the greater part of the trackage involved, and thus its electro-magnetic effect was cumulative with reference to the adjacent paralleling wires. The beautiful simplicity of this arrangement, however, is quite apparent. Referring to Fig. 4, it will be seen that under the new arrangement generators at the power station no longer feed the contact wire directly, but interposed between are auto-transformers, situated in the power station, having their centers grounded to the rails. The terminal voltage of the generators, as before, is 11 000 volts. The transformers raise this to 22 000 volts. One terminal of the transformer is carried to the contact wires and the other to feeder wires. These feeder wires are the ones previously used to parallel the contact wires.

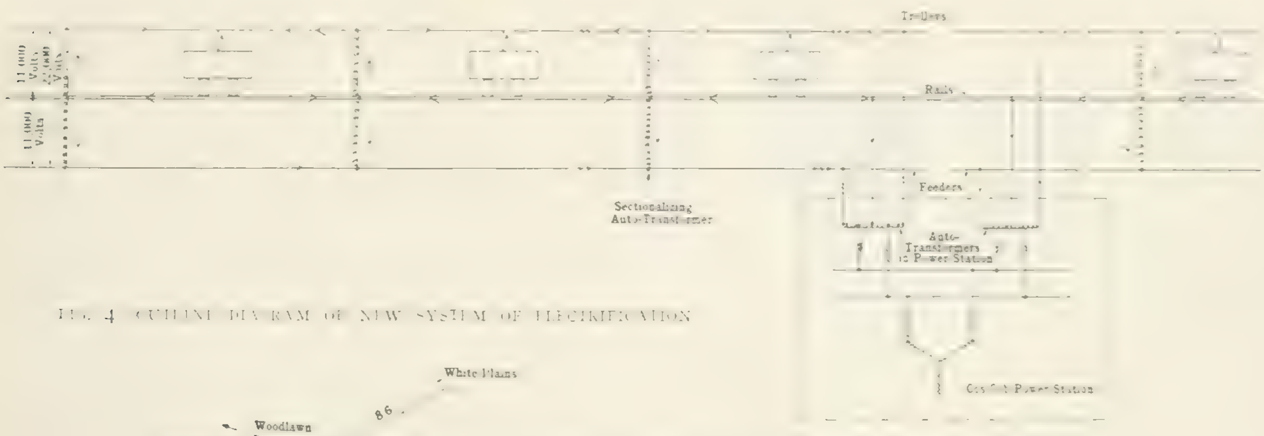


FIG. 4—OUTLINE DIAGRAM OF NEW SYSTEM OF ELECTRIFICATION

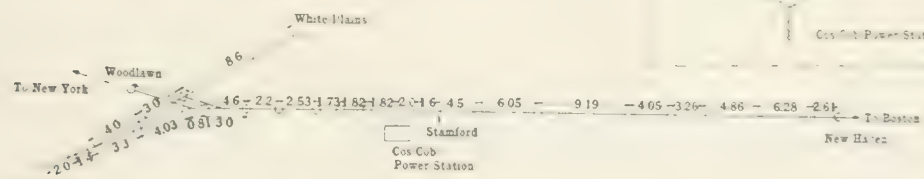


FIG. 5—DIAGRAM SHOWING LOCATION OF SECTIONALIZING SWITCHES AND TRANSFORMERS

The circles indicate these points and the dimensions are in miles.

At distances of every few miles, Fig. 5, along the main line, and located usually with reference to an already existing anchor and sectionalizing bridge, is

situated an outdoor type auto-transformer. This in turn has its center connected to the rails, one terminal connected to the contact wires and the other terminal to the feeder wire. The total line is therefore broken up into sections of short length. By reference to the arrows it will be seen that any train draws it current from the transformers on either side of it; and, providing it is situated midway between transformers, half of this current will complete its circuit through

Fig. 6—Arrangement of wires under a typical four-track bridge, 11 000 volts

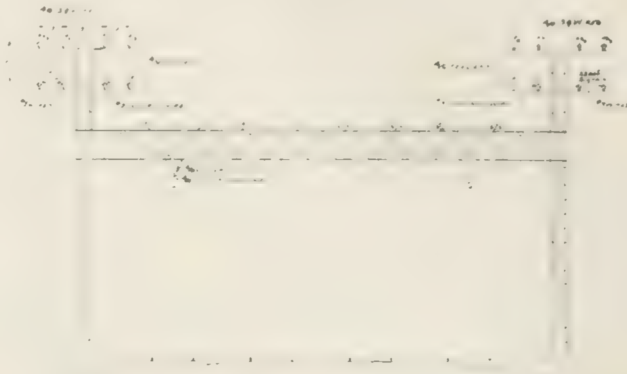


Fig. 7—Similar diagram for the 22 000 volt system showing wire arrangement

the rails and ground in one direction, and the other half through the rails and ground in the other direction, thus tending to neutralize its electro-magnetic effect upon adjacent telephone or telegraph circuits. In case a train is situated nearer to one transformer than to the other, it will draw the greater part of its current from this transformer and the smaller portion of its current from the more distant one. The net result, however, is the same; for it can be seen that the larger current multiplied by a shorter distance is again balanced by the smaller current multiplied by the larger distance. What is true electro-magnetically is true also in large measure electro-statically, for regarding the primary 22 000 volt circuit, which, as will be seen, is made up of the contact wire on one side and the feeder on the

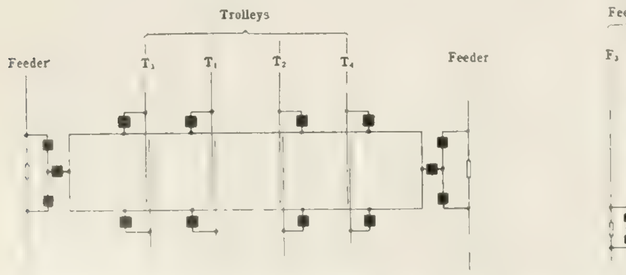


Fig. 8—Sectionalizing arrangement under the 11 000 volt system at a typical four-track bridge

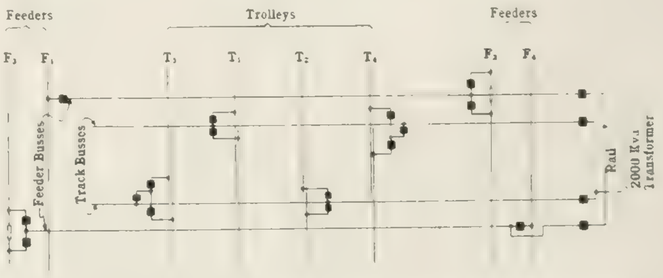


Fig. 9—Similar diagram for the 22 000 volt system

other, it now becomes possible to bring these two wires into the same general position with reference to outside circuits, and thereby balance their electro-static effects; obviously this is not possible when one side of the primary circuit consists of the rail and ground return. Electro-static disturbances are and always have been inappreciable in the case of the New Haven electrification; the point is mentioned herein as being a valuable consideration in other situations where these effects may be a larger factor.

It was prophesied that in addition to doubling the transmission voltage and eliminating practically all of the inductive disturbances, certain other advantages would follow from this arrangement. It is clear that the doubling of the transmission voltage has been effected without increasing the potential stress to ground, for although there are 22 000 volts across the complete circuit, yet the potential from either side to ground is only 11 000 volts. The arrangement, in fact, represents what is familiarly known in direct-current practice as the three-wire system, except that in this instance only one side of the circuit is loaded. There were many good reasons—chiefly difficulties at cross-overs and junctions—which led to the utilization of only one side of the circuit. Obviously this arrangement permits of extreme flexibility in the choice of transmission voltage, since across one side of the circuit the voltage may be raised to any practicable figure, leaving the voltage on the contact wires and rolling stock the same. For instance, in the case of the New Haven electrification the auto-transformers, as shown, have a one to one ratio, with eleven thousand volts across each side. For other conditions it would be quite feasible to use transformers with a ratio of say, four to one; *thus giving a transmission voltage of 55 000 volts, whilst retaining 11 000 volts on the contact wire.* It will at once be apparent that by the use of an additional wire a two-coil transformer arrangement could be used, which would possess advantages under certain conditions; the underlying principle,

however, is the same in either case. Several of the more recent electrification plans, including the Pennsylvania, show the adoption of the two-coil arrangement. It will be noted that the potential stress to ground on the generators at the power house has been materially reduced by the new arrangement.

Figure 10 shows the complete system of main circuit connections, exclusive of power station, under the old arrangement. A study of Figs. 6, 7, 8 and 9 will show the nature and extent of the changes involved. Fig. 11 shows the complete main circuit connections under the new arrangement. The power station connections, both old and new, are shown in Figs. 12 and 13. It will be seen that the changes to be made were considerable, particularly in view of the fact that the transition from one system to another had to be made without interference with the operation of trains, and this on one of the most congested pieces of trackage in the country. To do this without interrupting traffic required the making of many temporary connections and the perfecting of an arrangement which permitted the final changeover to be made easily and quickly. The important duties in connection therewith were delegated chiefly to Mr. E. J. Amberg, assistant engineer, to whose ability and painstaking thoroughness was due in large measure the successful accomplishment of the work. Plans were carefully laid, each step being prearranged in its proper sequence with relation to all other steps; the preliminary work extended over a period of eighteen months.

To make the *final* changeover from the old system to the new, and to do this simultaneously at the generating station, and on nearly 350 miles of trackage with the minimum interruption to traffic, presented problems of no inconsiderable difficulty. At some points the changes to be made were very small, merely the disconnecting of a few wires and the closing of certain switches; at other points a great deal of work and change was involved. Each man, however, had to do his part just right. It meant rapid, positive and exact coördination between a large number of separate individuals or gangs situated remotely from each other, and distributed over a large area. These different units had to be tied together through some central exchange; the load dispatcher, therefore, formed a natural clearing house for the issuance and receipt of instructions and reports. A mistake at any point by some man or set of men would have meant confusion and delay affecting the whole system. The work had to be largely performed in the darkness; the early hours of a Sunday morning were predicated by the lightness of the traffic requirements at that time. It was arranged that the few trains scheduled to run between the hours of 2:00 A. M. and 6:00 A. M. should be hauled by steam locomotives. Four hours, then, were available in which to ring out the old and ring in the new. Promptly on the appointed minute the generating station was shut down, thus automatically removing power from the whole system. Notification was given by the load dispatcher to all concerned that work might be started, and the race was on. Within two minutes of the issuance of the instructions to go ahead, the load dispatcher's telephone bell tinkled and the first distant gang reported themselves as having finished their task, and asked for further instructions. They were told to stand by and await orders. In quick succession came other reports and the same reply was given; and now at lengthening periods came the reports from those who had had more involved work to do. At 3:09 A. M., i. e., within 69 minutes from the start, the last report was in. At 3:10 those in the generating station had received word that all outside work on the 350 miles of track had been finished.

Meanwhile within the power station itself, wherein the changes to be made were of course much greater than at any other individual point, a panoramic performance like an over-stimulated beehive had been enacted. Every motion of a large number of hands had been made to count. At 3:21 A. M. all work within the power station was reported as finished. So far, then, everything had moved with the precision of a well-regulated and well-oiled clock. It now remained to test the results of this work and of the eighteen months' work which had preceded it.

At 3:25 A. M. the power station operators were told to start up the turbo-generators. At 3:34 the control and three-phase circuits were energized by very gradually building up voltage on them. At 3:44 this portion of the apparatus had been tested and found to be O. K. The real test, however, was still to come, and the main circuits were now energized; the voltage on these being most carefully but continuously built up by minute accretions extending over a considerable period. Full voltage was obtained at 4:30 A. M. and at 4:45 A. M. the entire system was pronounced ready for load. Regular trains Nos. 93 and 97, for which steam locomotives had been scheduled, were advised to operate electrically. This was done, the load from these being apparent at 5:25 A. M. and 5:26 A. M., respectively. Within a few minutes these trains tore past the power station and disappeared in a faint trail of sparks to the accompaniment of a triumphant blast from their sirens.

The final test, however, would come when a ground took place on one or more of the main track circuits. This would test not alone the efficiency of the protective devices, but the correct selective functioning of the line control aparatus as well. Under ordinary circumstances we might have had to wait several days or even weeks for a ground to take place; but a wet muggy night, combined with a steam locomotive which most obligingly halted and belched steam and smoke under an already defective insulator, quickened matters a little. Our suspense was short-lived; in a few minutes the distant insulator grounded. There was a shock and a response, within a fraction of a second the distant circuit breakers had tripped

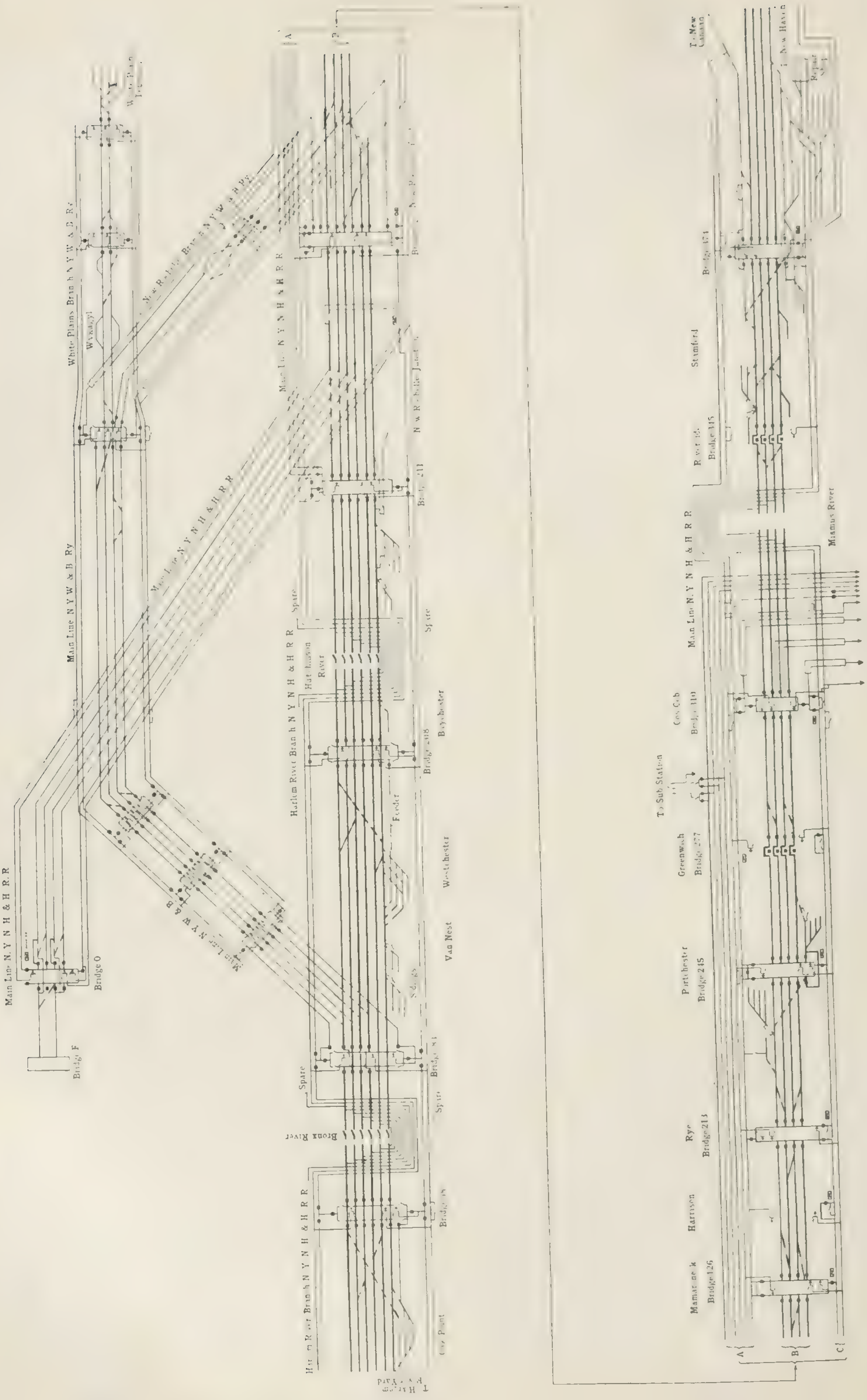
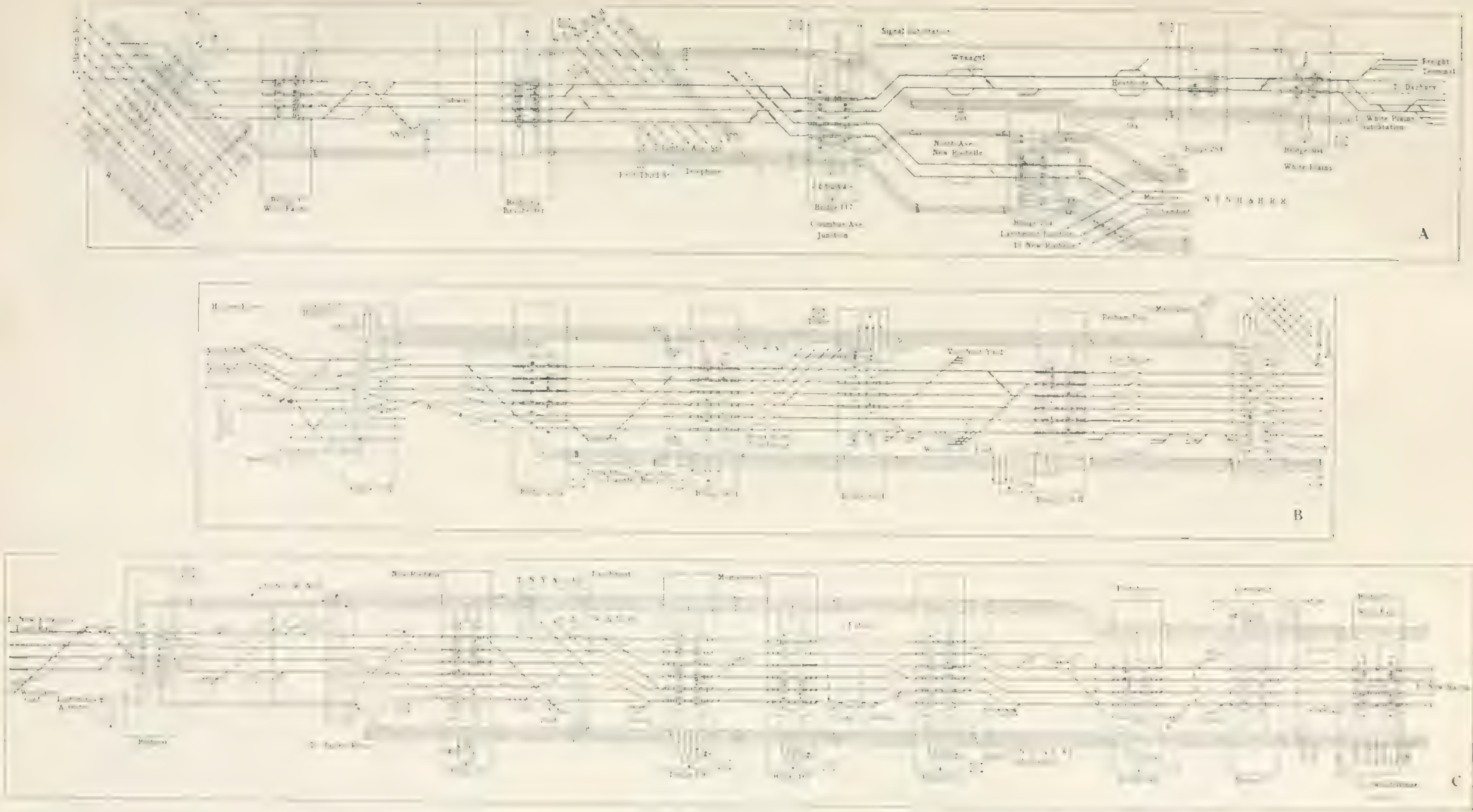


FIG. 10—GENERAL WIRING DIAGRAM OF THE NEW YORK, WESTCHESTER & BOSTON RAILWAY AND THE ELECTRIC ZONE OF THE NEW HAVEN RAILROAD, OPERATION AT 11 000 VOLTS—ORIGINAL POWER HOUSE LAYOUT SHOWN IN FIG. 12



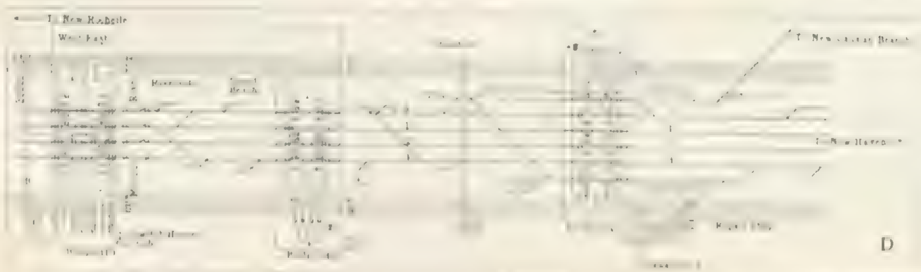


FIG. 13—GENERAL WIRING DIAGRAM OF THE [illegible]

[illegible] New York, Westchester & Boston Railway. [illegible] Harlem River Branch. [illegible] The [illegible] New Rochelle [illegible] will be [illegible] in the figure. When [illegible] and each will be [illegible] sections shown in broken lines. D—Distribution diagram [illegible]

and the line had cleared itself. Following the usual practice, the towerman on the spot again closed the circuit breakers and the short-circuit was repeated. The whole aparatus functioned perfectly.

At 5:31 A. M. the operating department was advised that full normal service might be resumed. Such a result could only have been achieved by the very best kind of team work on the part of all concerned. The changes were made under the direct and personal supervision of Mr. Wm. S. Murray, acting in his official capacity as consulting engineer to the railroad company. All matters pertaining to the 350 miles of tracks were delegated to Mr. H. Gilliam, who was assisted by Messrs. Tyree and MacKay. As before stated, Mr. E. J. Amberg was responsible for the preparatory work in general and for the internal changes to the power house circuits, in which latter he was ably assisted by Mr. B. Wheeler. There were a number of others who rendered valuable service in many other directions and places, and contributed their full quota to the successful issue.

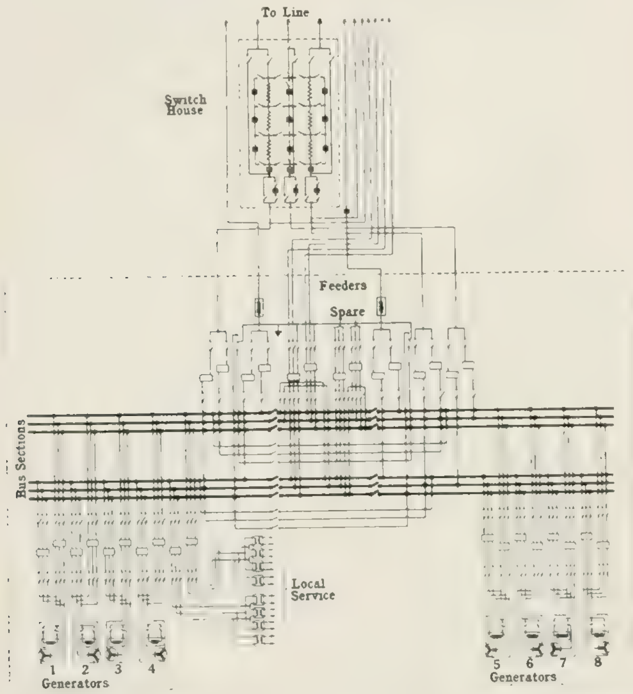
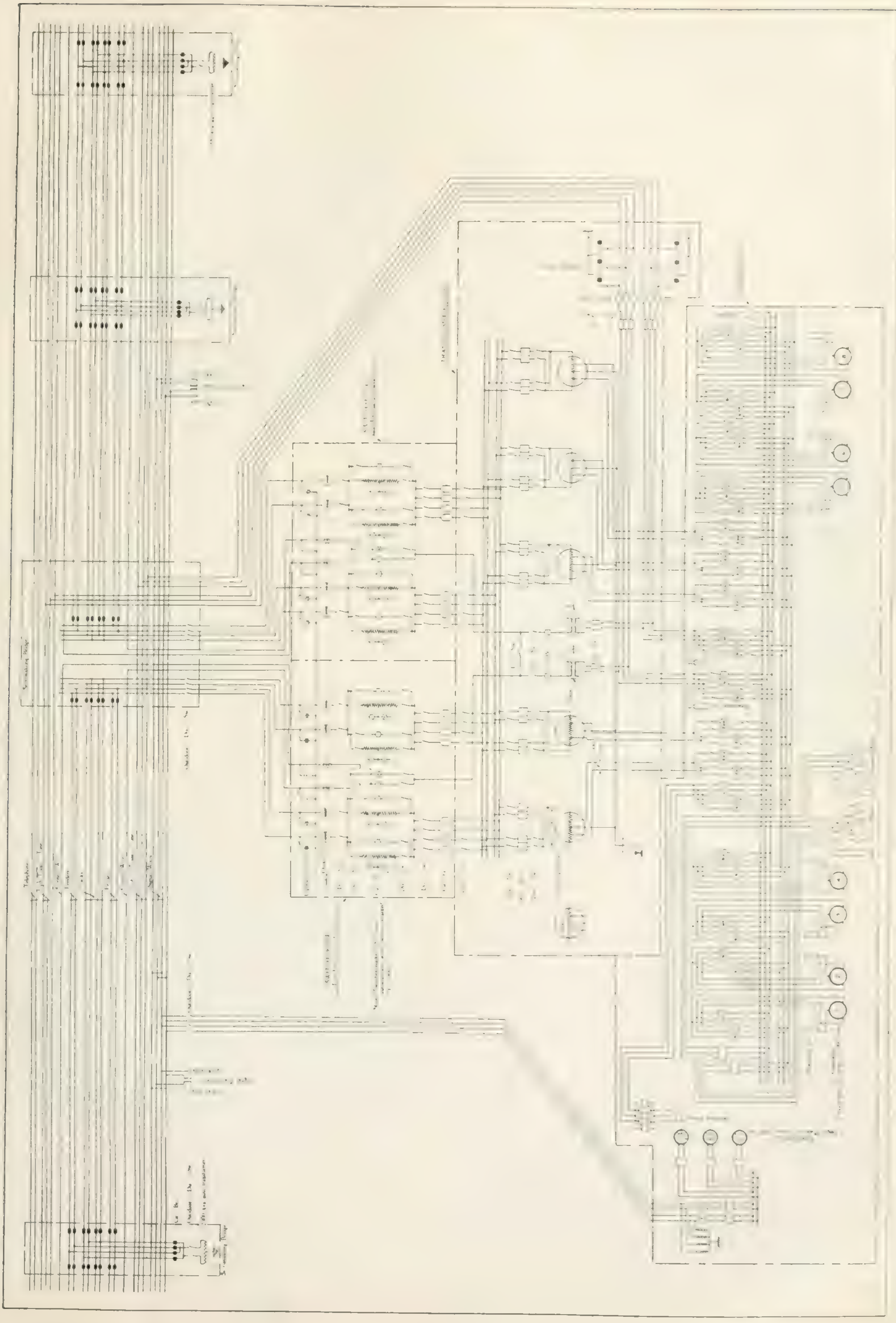


FIG. 12—SCHEMATIC DIAGRAM OF H. T. BUS AND CONNECTIONS AS USED FOR 11 000 VOLTS AT COS COB POWER HOUSE

Immediately after the inauguration of the new service the writer visited the headquarters of one of the local telegraph and telephone systems and inquired as to the results to be noticed on their lines. One of the officials stated that whereas hitherto it had always been necessary to most carefully adjust the compensating and other apparatus on *account* of inductive disturbances, they now were adjusting in the endeavor *to find* any remaining trace of the disturbing effect; but so far without success.

The results which have been maintained during the month succeeding these changes have fully justified the expectations of those who were responsible for the inception of the primary idea and for its successful consummation as a working electrification. The primary "three-wire" system" idea was rough hewn and presented as an offshoot from the mind of Mr. E. H. McHenry, formerly vice-president of the New Haven Railroad in charge of engineering. It was reviewed by Mr. Chas. F. Scott, who proposed the arrangement of circuits and transformers, described herein as best suited to the particular conditions; whereas the engineering adaptation of the general scheme to the existing system was worked out by Mr. Wm. S. Murray, formerly electrical engineer for the company. Professor Scott's preliminary calculations had shown the large relief from inductive distrubances which we could expect. The actual results show the relief to be even greater than was anticipated. This is a truly gratifying accomplishment and one which not only reflects the greatest possible credit on all concerned but—what is of much more importance—breaks down and removes completely the last slender barrier which has remained in the way of the full acceptance and realization in all countries, of the splendid possibilities of the single-phase system for general electrification work.

Most electrifications start in a small way around terminals and congested areas, and in the future will gradually grow outward until they meet and overlap other similarly growing systems. A high voltage alternating current in a single overhead contact wire has shown itself to be the most elastic and commercially efficient suit of clothes that a growing electrification can wear. It permits the simultaneous operation of single-phase, three-phase and direct-current-rectifier rolling stock from the same contact wire "without breaking gauge." With direct current this is not true; and when once committed to its use we are often in the position of one who is staggering along under a constantly growing weight, which he dare not and may not let fall. To join up the one system with the other involves either costly complication or a break of gauge. All who have had much experience with either or both, know with certainty the inefficiency and expense which follows. Unbiased and competent engineers, of course, would not hesitate for a moment to recommend the use of direct current in situations where all present and future conditions warrant it, but the consensus of opinion in Europe and America has shown that these situations are special and rare, and so far as can be seen will probably become more so. The single-phase system has come into its own; the results described herein are but a further indication of this. These results constitute the last needed strokes of the axe, dealt boldly yet surely by the arms of those pioneers who blazed the original trail, thus opening up the way into the land of future achievement.



Polar and Circular Oscillograms and Their Practical Application

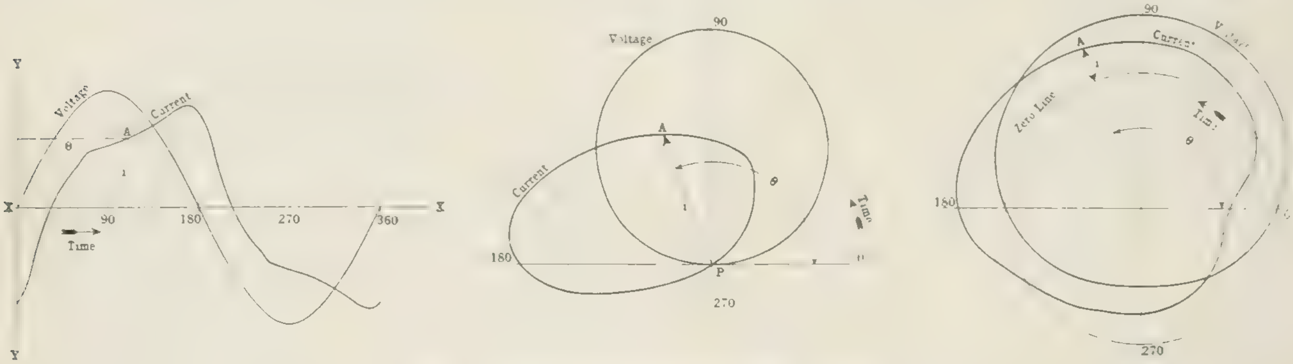
L. W. Chubb

FOREWORD—In a recent article a new harmonic analyzer was described which works mechanically from a polar or circular curve of the wave to be analyzed. The present article describes the apparatus and method used in taking polar oscillograms, brings out some additional uses of the polar curves and shows some short cuts and new methods of calculation.*

Variations and fluctuations in any quantity or mathematical function are conveniently expressed graphically with curves and waves. Such curves may be used to give only a mental picture of a certain variable function or may be used for more exact measurements and calculations. When quantitative results are to be expressed it is necessary to refer the curve to certain coördinate axes or reference points. To do this several systems of coördinates have been used but only two, the rectangular or Cartesian, and circular or polar systems are in common use. In the former plane curves are referred to two perpendicular lines or axes, and in the latter the points of the curves are located by their distance from a point called the pole and the angle subtended between a reference line through the pole and the radius vector or line joining the pole and the point in question.

Oscillograms or photographic records of electrical waves are generally recorded on rectangular coördinates on a moving photographic plate or a film wrapped around a revolving cylindrical drum. Two distinct types of curves are recorded by the oscillograph, those which are periodic and those which show transient phenomena. Transient curves should properly be expressed in rectangular form but periodic waves can profitably be recorded in circular or polar form.

Figs. 1, 2 and 3 show three graphical methods of expressing the periodic exciting current and voltage of a transformer. Fig. 1 shows the common form of curve in which the cycle is referred to two perpendicular lines. The abscissa or horizontal scale shows time or electrical degrees and the ordinate or vertical scale shows the variations of current and voltage above and below the zero value. Fig. 2 shows the polar curves of the same functions, and any point such as A on the current curve is located by the angle Θ between the horizontal axis and the radius vector i and the distance i (amperes) from the pole P. Fig 3 shows another polar curve or circular curve in which the same point A is located by the angle Θ and the radial distance from the zero line or reference circle. Figs. 2 and 3 are both polar curves, the only difference being that in Fig. 3 the radius vector is a constant (radius of the zero circle) plus the value of current or voltage, while in Fig. 2 these functions are measured directly from the pole in the plus or minus direction on the radius vector. With the true polar curve, Fig. 2, the two lobes or half cycles of the curves are coincident (when only odd harmonic components are present) as the negative values are measured in a direction opposite to the angular reference line or radius vector, and the sequence of values in the two half cycles of the curves are the same except for sign.



FIGS. 1, 2 AND 3 VOLTAGE AND CURRENT CURVES

Fig. 1—As referred to rectangular axes. Fig. 2—As referred to a polar axis. Fig. 3—As referred to a circular zero line.

Oscillograms of periodic curves can best be taken in the form shown in Fig. 3, but in some cases the true polar form is better as will be shown later. To record photographically the motions of the spot of light of the oscillograph in polar or circular form a sensitive disc film is made to revolve about its center and the spot of light made to vibrate radially on the film. Fig. 4 shows the film holder used in taking circular oscillograms. It consists of a light tight casing in which the film is revolved at synchronous speed on the shaft of a small motor. The motor is mounted on the back of the apparatus and its shaft extends through a felt bushed hole to the inside of the casing. A flywheel

*See "The Analysis of Periodic Waves" in the JOURNAL for February, 1914.

of sheet steel 10 inches in diameter is mounted on the shaft and the photographic film of the same diameter is secured to the shaft directly in front of the flywheel. Fig. 5 shows an exploded view of the film holder with the parts indicated. The front of the casing is secured with wing-nuts and can easily be removed in the dark room or in a bag to load or withdraw the films. A radial slot *S*, about four inches long, is arranged with a sliding shutter. This shutter is provided with a wedge shaped opening so that as it slides past the slot the exposure at the different distances from the center will be proportional to the radius and equalize the impression on the film at all points. The extension *D* at the bottom of the apparatus is pushed in or pulled out to operate or slide the shutter. On the face of the casing is a brass plate *P* which fits on the film holder slots of the oscillograph, and when the apparatus is in place, the spot of light from the oscillograph element vibrates radially in and out from a zero position near the center of the slot. Since the film is run at synchronous speed the shutter can be left open for several revolutions of the film and each part of the film will be exposed several times instead of just once, as is the case with the usual oscillographic apparatus.

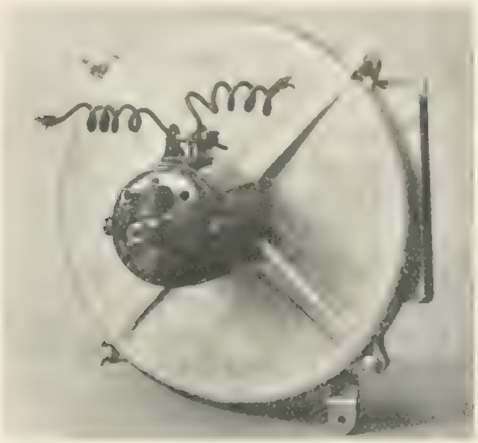


FIG. 4—FILM HOLDER FOR USE IN TAKING CIRCULAR OSCILLOGRAMS

FIG. 5—EXPLODED VIEW OF FILM HOLDER
A—Flywheel *B*—Film

Fig. 6 shows the apparatus attached to the oscillograph, and also the apparatus used to tell when the film is running at synchronous speed. The natural drive for the film would be a synchronous motor, but such a motor is not practical because often sufficient alternating current cannot be taken from the circuit without disturbing the conditions of test. For this reason the film motor is a series commutator motor which can be run on the same circuit, another alternating current circuit or on a direct-current circuit. Synchronous speed is indicated by observing a vibrating reed *R* through a stroboscopic slot in a small cylindrical extension on the shaft of the motor. The reed is very small and is arranged with a movable fret *F* so that its natural period of vibration can be adjusted to agree with the frequency of the circuit and made to vibrate electromagnetically with a very feeble current. The speed of the motor is varied until the vibrating reed observed through the stroboscopic slot is apparently standing still. When synchronous speed is thus indicated the shutter is operated by pressing the lever *L*. Usually two exposures are made, one to record the periodic waves and the other, with the oscillographic switches open, to record the zero lines or reference circles.

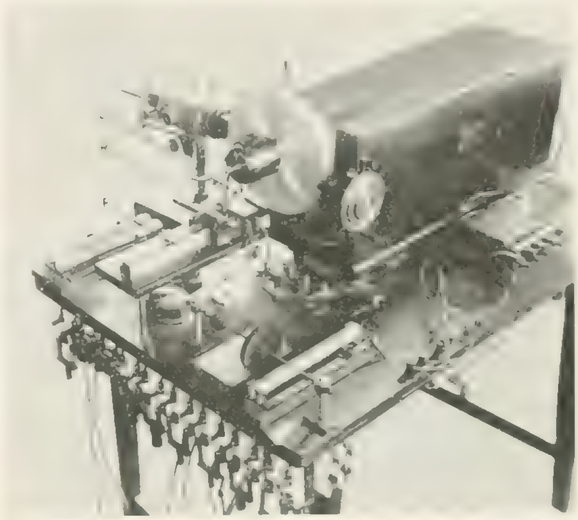


FIG. 6—APPARATUS FOR TAKING CIRCULAR OSCILLOGRAMS

Until an engineer is used to the polar pictures of electrical waves, they seem somewhat confusing and do not give at a glance the clear conception that the rectangular pictures do. However, for general usefulness and accuracy they have proved to be much more valuable than the former type as a single cycle is several times as long and this extension of the time scale and the geometric form of the curve allow more accurate sub-division and more simple and accurate calculations of phase angles, harmonic analysis, square root of mean square values, power in watts, power-factor, wave shape distortion, distortion factor, etc.

The *method* of using the circular oscillograms for harmonic analysis has already been covered in the former article. The other constants and ratios mentioned above can be calculated directly from the circular oscillogram or indirectly from the results of the

harmonic analysis. In the following these methods and their proofs will be given.

EFFECTIVE OR ROOT MEAN SQUARE VALUES

In alternating-current circuits the effective value, or square root of the mean square value, of current and voltage is of the greatest importance. When possible the effective values of volts and amperes can most readily be measured with the alternating-current ammeter or voltmeter, both of which give the square root of the mean square value. Often, however, it is impossible to obtain meter readings and in design and analytical problems it is necessary to know the effective values of a wave or the resultant of two or more component waves.

The conventional method of taking vector sum or difference of component waves is not correct except for pure sine waves, and in many cases distortions of electric waves are such that vector diagrams and other conventional methods of calculation are not sufficiently accurate. Effective values may be worked out from the rectangular curve by squaring the ordinates, drawing the curve of squares, determining the average height with a planimeter and extracting the square root. Such a method is laborious and time can be saved by plotting the curve in polar form and measuring the area of the curve which is, of course, proportional to the mean square ordinate. The root-mean-square values can be obtained directly from the circular oscillogram with the aid of a planimeter, for if the net area of the curve be assumed to be the difference between the area enclosed by the curve and that of the zero circle, then,—

The root mean square value of a circular curve is the square root of the ratio of the net area of the curve to π

Thus the effective voltage is,—

$$E = K_e\sqrt{\frac{A_e}{\pi}} = K_e\sqrt{\frac{A-A_0}{\pi}} \text{ ....(1)}$$

Where, E = The square root of the mean square voltage
A = Area of the circular curve
A_0 = Area of the zero circle
$A_e = A-A_0$ the net area of the curve
π = 3.1416
K_e = the scale constant.

When the areas are in square inches the scale constant K_e is expressed in volts per inch. If a true polar curve is measured there is no zero circle and A_0 becomes zero.

To prove the above formula let:—

Θ = time angle in radian measure
e = $f(\Theta)$ = the instantaneous value of voltage
e_0 = the radius of zero circle in inches
R_e = Distance in inches of curve from center at any position Θ
K_e = calibration constant in volts per inch

$$\text{Then:—}R_e = \frac{e}{K_e} + e_0$$

Assuming all integrals complete and between the limits of zero and 2π the areas will be.—

$$A = \int\frac{\left(\frac{e}{K_e}+e_0\right)^2 d\Theta}{2}$$

$$A_0 = \int\frac{e_0^2 d\Theta}{2}$$

Substituting these values of area in the right hand member of equation (1) we get:—

$$E = K_e\sqrt{\frac{\int\left(\frac{e}{K_e}+e_0\right)^2 d\Theta - \int e_0^2\, d\Theta}{2\pi}}$$

or expanding and cancelling,—

$$E = K_e\sqrt{\frac{\int\left(\frac{e}{K_e}\right)^2 d\Theta}{2\pi} + \frac{\int\frac{e e_0}{K_e}\, d\Theta}{\pi}}$$

The last term is equal to zero between the limits 0 and 2π so that the formula reduces to $E = \sqrt{\frac{\int e^2 d\Theta}{2\pi}}$ which is the square root of the mean square value.

The effective value can also be obtained readily from the analysis or Fourier series of the circular curve.

The root-mean-square value of a distorted wave is equal to the square root of the sum of the square of the root-mean-square values of its harmonic components of different frequency.

The root-mean-square value of a Fourier series is equal to the square root of half of the sum of the squares of the coefficients of the several sine and cosine terms.

$$\text{R.M.S.} = \sqrt{\frac{A_1^2+A_2^2+A_3^2+\ldots A_n^2+B_0^2+B_1^2+B_2^2+B_3^2+\ldots+B_n^2}{2}}$$

POWER OR WATTS

The power in a circuit cannot always be measured with a wattmeter but the voltage and current waves can be recorded accurately, by the oscillograph, in their proper phase relation and the mean power worked out from the record. As an example there is not time to balance or read a wattmeter during a short operation such as making an electric weld or a heavy current test. Also in testing resonant circuits the ordinary meters cannot be used because they are inductive and may disturb the conditions of the circuit. In such cases the oscillograph, which is quick and practically non-inductive, will record the current and voltage waves faithfully, and the record will tell the whole story. The true watts or mean product of two alternating waves can be figured from the oscillogram which has the curves recorded in their proper phase relation.

Fig. 7 shows in full lines a current and voltage wave each referred to a separate zero circle. Let e and i (both functions of Θ) be the instantaneous values of voltage and current respectively, and K_e and K_i, the scale constants in volts per inch and amperes per inch. The variations of the waves are measured from the zero circles whose radii are e_0 and i_0 inches. Let R_e and R_i be the distances (in inches) of the curves from the center of the circles. Then,—

$$R_e = \frac{e}{K_e} + e_0$$

$$R_i = \frac{i}{K_i} + i_0$$

The first operation in the calculation is to construct the dotted polar curve and small circle at the center. The former is laid off with dividers and at each angular position Θ, the radius r_1 is equal to the radial distance between the voltage and current waves. Thus $r_1 = R_e - R_i$. The small dotted circle at the center has a radius equal to its radial distance between the two zero circles, thus, $r_2 = e_0 - i_0$.

Let the net area of the voltage wave A_e be the difference between the area enclosed by the voltage wave and the area of the voltage zero circle. This net area can be measured accurately with a planimeter. Similarly let A_i be the net area of the current wave. Let A_x be the area of the dotted difference curve and A_y the area of the dotted circle. The several areas when measured in square inches can be used to calculate power for:—

True power in watts is equal to the product of the scale constants of the voltage and current waves divided by 2π and multiplied into a quantity consisting of the net area of the current wave plus the net area of the voltage wave, minus the area of the (dotted) polar curve (whose radius vector is equal to the distance between the current and voltage curves), plus the area of a circle whose radius vector is equal to the difference between the radii of the two zero circles.

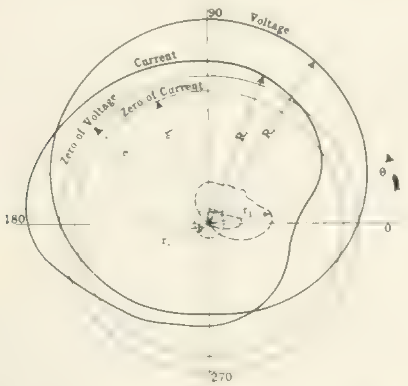


FIG. 7—DIAGRAM SHOWING CURRENT AND VOLTAGE CURVES PLOTTED TO DIFFERENT BASE CIRCLES

$$W = \frac{K_e K_i}{2\pi}\left[A_i + A_e - A_x + A_y\right]$$

For simplicity in the proof of the power formula it is to be understood that all integral terms are complete and between the limits of zero and 2π.

$$A_i = \int \frac{R_i^2\, d\Theta}{2} - \int \frac{i_0^2\, d\Theta}{2}$$

$$A_e = \int \frac{R_e^2\, d\Theta}{2} - \int \frac{e_0^2\, d\Theta}{2}$$

$$A_x = \int \frac{(R_e - R_i)^2\, d\Theta}{2} = \int \frac{R_e^2\, d\Theta}{2} - \int R_e R_i\, d\Theta + \int \frac{R_i^2\, d\Theta}{2}$$

$$A_y = \int \frac{(e_0 - i_0)^2\, d\Theta}{2}$$

Combining these areas as in the formula and cancelling terms the formula reduces to:—

$$W = \frac{K_e K_i\left[-\int \frac{i_0^2\, d\Theta}{2} - \int \frac{e_0^2\, d\Theta}{2} + \int R_e R_i\, d\Theta + \int \frac{(e_0 - i_0)^2\, d\Theta}{2}\right]}{2\pi}$$

[illegible] ther:—

$$W = \frac{K_e K_i\left[\int R_e R_i\, d\Theta - \int e_0 i_0\, d\Theta\right]}{2\pi}$$

Substituting $R_e = \left(e_0 + \frac{e}{K_e}\right)$ and $R_i = \left(i_0 + \frac{i}{K_i}\right)$ expanding and cancelling $W = \frac{K_e K_i\left[\int \frac{e_0 i\, d\Theta}{K_i} + \int \frac{i_0 e\, d\Theta}{K_e} + \int \frac{ei\, d\Theta}{K_e K_i}\right]}{2\pi}$

The first two terms in the bracket are zero when integrated for a complete cycle so the formula reduces to:—

$$W = \frac{1}{2\pi}\int ei\, d\Theta$$

which is the familiar expression for the average power for a complete cycle.

The Fourier series of the current and voltage can be used very easily to figure power for:—

Power in watts is equal to half of the sum of the products of the corresponding coefficients of the terms of the Fourier series of the current and voltage waves. This expression is old and need not be proved.

POWER-FACTOR

From the foregoing, the power-factor which is the ratio between the true power in watts and the product of the root mean square values of the volts and amperes can be written:—

$$\text{Power Factor} = \frac{\frac{K_e K_i (A_i + A_e - A_x + A_y)}{2\pi}}{\sqrt{\frac{K_e^2 A_e}{\pi}}\sqrt{\frac{K_i^2 A_i}{\pi}}}$$

The symbols are the same as used above. This formula requires no proof as the terms of both numerator and denominator have already been proved. This expression shows by cancellation that the power-factor is independent of the scale constants K_e and K_i and the formula reduces to the more simple form:

$$\text{Power Factor} = \frac{A_i + A_e - A_x + A_y}{2\sqrt{A_e A_i}}$$

The power-factor can also be obtained quite easily by dividing the harmonic expression for power by the product of the harmonic expressions of the effective voltage and current given above.

WAVE SHAPE DISTORTION

The present specification of wave shape as given by the American Institute of Electrical Engineers states that the maximum deviation of the wave shall not be more than ten percent of the maximum ordinate of the equivalent sine wave. To check a wave under this specification from the rectangular curve it is necessary to find the equivalent sine wave (or sine wave with the same effective value). Place this wave in such phase position with the wave tested that the maximum deviation will be a minimum, then measure this minimum maximum deviation and calculate the percentage of the maximum ordinate of the equivalent sine wave. This process of calculation is very laborious and inaccurate, but if the wave is recorded as a polar curve directly by the oscillograph or changed to a polar curve from a rectangular or circular oscillogram, the deviation can be figured out as follows:—

First measure the area of the polar urve with a planimeter and represent the equivalent sine wave by a circle which has an equal area. This circle drawn on a piece of thin or transparent paper, should then be placed over the polar curve of the wave in question and a needle should be driven through a point on the circumference of the circle placed over the pole of the other curve. The small piece of paper is then to be moved around the needle as a pivot until the minimum maximum deviation between the two curves measured on a radius vector is obtained. This difference expressed in percent of the diameter of the circle is the final result.

The harmonic expression cannot be used conveniently to check wave shapes in accordance with the present specifications.

SUMMARY

Practically all electrical waves in alternating-current circuits have an average value of zero for a complete cycle, that is, they are sine waves or distorted waves containing harmonic components of various

FIG. 8—CIRCULAR OSCILLOGRAM OF THE VOLTAGE ACROSS A CONDENSER AND THE CURRENT THROUGH IT, TOGETHER WITH THE DIFFERENTIAL OF THE VOLTAGE WAVE

A—Voltage zero circle. *B*—Current zero circle. *C*—Voltage impressed on condenses. *D*—Condenser current.

frequencies but containing no constant term or direct-current component. For such waves all of the above methods of calculation are mathematically correct. Pulsating waves, the waves in either the direct or alternating-current side of a rectifier, the waves in unsymmetrical high voltage circuits in which corona is present and in such circuits as the shunt field of a generator are periodic waves, but the average value through a cycle is not zero and the short-cut methods of calculating effective values, power and power-factor from circular curves cannot be used without troublesome corrections. This is true because in all cases the terms of the form $K \int f(\Theta) d\Theta$ have been considered zero while if $f\Theta$ contains a constant term or direct-current component this would not be so.

The solutions with the coefficients of the terms of the harmonic analysis are, however, correct in all cases because the harmonic expression or Fourier series of a wave will include the constant term B_0. For this reason solutions of all problems with distorted periodic waves should be worked out by the harmonic method if there is any possibility of direct-current components being present, provided the work can conveniently be done with a mechanical analyzer and without troublesome preparation before analysis.

Other constants and ratios can easily be obtained from the harmonic expression, such as the form-factor of a wave, which is the ratio of the root mean square value to the average value (disregarding sign).

In a technical paper before the American Institute of Electrical Engineers* a new and better potential wave shape standard has been recommended which states that when the potential wave is impressed upon a condenser the ratio of the apparent reactance to the true reactance on the equivalent sine wave of the same fundamental frequency shall not exceed a certain figure. This *distortion ratio,* as it is called, *is* really *the ratio between the root mean square value of the first differential of the wave and the root mean square value of the wave.* Such a ratio can more accurately and as easily be found with the oscillograph and subsequent harmonic analysis.

It is evident that the ratio between the effective values of this first differential and the original function is:—

Distortion Factor

$$= \frac{\sqrt{\dfrac{A_1^2+4A_2^2+9A_3^2+\dots n^2A_n^2+B_1^2+4B_2^2+9B_3^2+\dots n^2B_n^2}{2}}}{\sqrt{\dfrac{A_1^2+A_2^2+A_3^2+\dots A_n^2+B_1^2+B_2^2+B_3^2+\dots B_n^2}{2}}}$$

or:— Distortion Factor $= \sqrt{\dfrac{\Sigma n^2A^2+\Sigma n^2B^2}{\Sigma A^2+\Sigma B^2}}$

If the distortion ratio is defined mathematically as above its use can be extended to compare current waves as well. The distortion factor of a current wave can be taken by impressing the wave on an inductance and taking the ratio between the apparent reactance and the true reactance at the same fundamental frequency. The calculations from oscillograms by harmonic analysis are the same for both current and voltage waves. The method is as simple and accurate as the experimental methods and has the advantage of showing what the distortions and causes of high distortion factor are.

A compromise between the oscillographic and experimental tests can be made. Fig. 8 shows the voltage across and the current through a condenser. If the voltage wave had been a sine wave the current would have been a sine wave,—

$$I=2\pi fCE$$

and as the ratio of the apparent reactance to the true reactance of a condenser is the same as the ratio of the current through the condenser on the distorted voltage wave to that which would flow on a sine wave it is evident that:—

*Proc. A. I. E. E., February, 1913.

$$\text{Distortion factor} = \frac{I}{2\pi f C E}$$

Where I = the effective value of the condenser current.
E = the effective value of the voltage wave.
f = the fundamental frequency.
C = the capacity of the condenser in farads.

If the distortion factor of a current wave is desired a circular oscillogram of the current and the voltage across an inductance should be taken and it can easily be shown that,—

$$\text{Distortion factor} = \frac{E}{2\pi f L I}$$

Where E = the effective voltage across the inductance.
I = the effective current flowing.
L = the inductance in henrys.

These compromise methods have the advantage of showing the wave tested and also the differential wave which exaggerates any distorting harmonics.

CONCLUSIONS

This discussion has been limited to the direct application of the circular oscillogram in harmonic analysis and in calculating directly a few of the common electrical functions and ratios. The use for harmonic analysis effective values, power and power-factor are, of course, the most important. The short-cut methods of calculating power and power-factor are not accurate when the power-factor is very low, but in all cases when these quantities must be measured with the oscillograph the new methods with the circular pictures are more accurate and much quicker than with the old rectangular oscillograms.

Throughout the discussion it has been assumed that th[illegible] the fundamental, but it is well before closing to call attention to the many cases in which an unsymmetrical machine, for instance a machine in which the number of armature slots is not a multiple of the pairs of poles will have a different cycle for each pair of poles. If such dissymetry is present, the true fundamental is the revolution of the machine and in order that the photographic impression of the successive revolutions of the circular film be coincident and the correct harmonic analysis obtained it is necessary to run the film at the same speed as the machine and show as many alternations in the wave as there are poles on the machine. It is, therefore, evident that the nominal frequency of the machine is an upper harmonic, and if there is an even number of pairs of poles the nominal frequency will be an even harmonic. Serious errors are sometimes made by analyzing the single cycle of an electrical wave derived from an unsymmetrical multipolar machine. Such an analysis will often miss a very pronounced ripple which is a harmonic component of the full revolution and give other components which are not present at all. Circular oscillograms with but a single cycle per revolution will indicate dissymetry at once as the successive cycles of the machine will not coincide at certain places. They will thus indicate when the analysis and calculations must be figured with the revolution as the fundamental, and another picture taken at machine speed will give a record from which the true analysis can be made.

Synchronous Booster Rotary Converters*

J. L. McK. Yardley

THE ADDITION of the synchronous alternating-current booster to the simple rotary converter has introduced new elements in the design and modified old ones in a manner that is not generally understood. The purpose of the booster is to make it possible to obtain a variable continuous voltage from the converter. Commercially, this method is a direct parallel to the induction regulator method and the split pole converter method of obtaining a variable continuous voltage, all of which are used to give a voltage range usually of 15 percent below and above normal. The method employing field control on a simple rotary converter with external reactance is not applicable for a range of more than five percent below and above normal on account of the large amount of wattless current in the converter armature, producing heating and bad commutation, and also the large amount of external reactance involved. For example, with 20 percent reactance in the leads to a simple converter carrying full-load current at normal voltage and unity power-factor, then, to operate at full-load current 105 percent voltage, the field must be increased so as to introduce a leading wattless component of 25 percent, or 0.25×20 percent = 5 percent, the desired rise in voltage. The power-factor will be $\frac{100}{\sqrt{100^2 + 25^2}} = 97$ percent leading. The I^2R loss in the tap coils of the converter will be increased 50 percent over the loss at the 100 percent voltage, current and power-factor conditions.*

The most satisfactory type of booster rotary converter so far developed has revolving armatures and stationary fields for both the converter and the booster. The booster armature is mounted on the shaft between the collector rings and the converter armature, and the booster and converter frame are mounted side by side on a common bed plate. In this construction the windings on the booster armature are connected to the collector rings on the one side and to the converter armature taps on the other. On the converter a closed circuit winding of lap-wound diamond-shaped coils is employed. On the booster the armature winding is also made of lap-wound diamond-shaped coils. This winding is, how-

*Revised from a lecture by the author at The Westinghouse Club, Mar. 5, 1914.

*See curves in article by the author in the JOURNAL for Sept., 1913.

ever, not closed on itself, but is separated into as many groups of coils as there are taps on the converter armature winding, these groups of coils being connected to the taps of the converter armature winding and to the collector rings in the sequence of rotation.

THE REQUIREMENTS OF THREE-WIRE OPERATION

It is not always necessary to have as many groups of coils on the booster armature as there are taps on the converter armature. For two-wire operation, two-phase and six-phase booster converters could readily be made with the booster having only half as many windings as the converter has taps, if the design worked out well in other respects, and, theoretically speaking, for a three-phase booster converter a booster could be supplied having two-thirds or one-third as many windings as there are taps on the converter winding. But a booster rotary converter can be operated on a three-wire system only where the booster has as many windings as the converter has taps. Assume a six-phase, two-pole booster rotary converter having three groups of coils in the booster

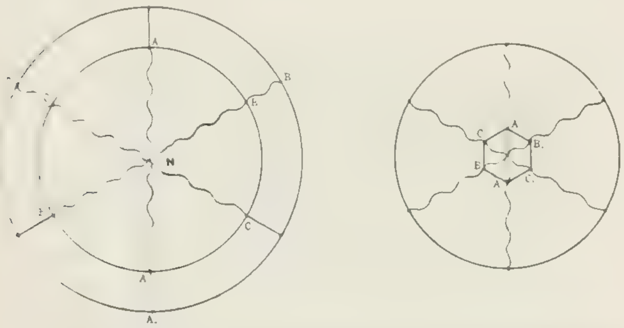


FIG. 1—DIAGRAMS SHOWING SHORT-CIRCUIT CONDITIONS RESULTING WHEN A BOOSTER OF THREE GROUPS OF COILS IS CONNECTED TO A CONVERTER WITH SIX ARMATURE TAPS FOR THREE-WIRE SERVICE

armature winding and six taps on the converter armature winding. If, in Fig. 1, the circle $ABC A_1 B_1 C_1$ represents the alternating voltage at the collector rings to which the transformers AA_1, BB_1 and CC_1 are connected with their middle points connected to form a neutral at N, and if the booster field is excited, it is plain that the voltage generated by the three-phase booster armature windings B_1B_2, A_1A_2 and C_1C_2 does nothing except force short-circuit currents through the transformer, booster and converter windings. The equivalent short-circuit is shown at the right in Fig. 1. With windings connected at N, the circle A_2, B_2, C_2 remains coincident with A, B, C, A_1, B_1.

REVOLVING FIELD BOOSTER ROTARY CONVERTERS

It is probable the suitability of booster rotary converters for three-wire operation was first brought into question when one of the manufacturers endeavored to use a standard three-phase open star type of winding on a booster in connection with a six-phase converter. It made an excellent selling argument for reliability of operation to say that the field of variable voltage service would be covered by a simple combination of two fully developed and standardized pieces of apparatus. The bed plate or the collector end pillow block of the simple converter was to be extended to carry the stationary frame and armature windings of the booster and the shaft of the simple converter was to be extended to carry the rotating field of the booster. In this connection it is desired to direct attention to some of the difficulties which must have been experienced in thus applying to variable voltage service apparatus already developed for constant voltage service. It will be seen that these difficulties extended practically to all parts of the machine.

The largest synchronous booster converter thus far built is provided with a booster of only 550 k.v.a. capacity approximately at normal full load. The speed and number of poles of the booster is determined by the speed and number of poles of the converter. The speed and number of poles of standard generators are determined purely on a cost basis and are made such as to give for the least cost the best rating which may be obtained from them in accordance with A. I. E. E. and manufacturers' rules governing rating. Now it invariably happens that the best speed and number of poles from the point of view of economy for an alternating-current generator of this size are different from those values dictated for the booster on account of its being direct-connected to the converter. The demands of this combination with the converter require, therefore, that the generator be built at a much lower speed and with a greater number of poles than the standard generator of the same rating. Owing to the great number of poles employed, a narrow machine of comparatively large diameter resulted. The type of armature winding was divided into a number of parallel low voltage circuits—one per collector ring per pair of poles. These circuits were connected at one end to the low-tension transformer leads and at the other end to the collector rings in proper sequence. In designing this winding it was further necessary to consider that when the booster is operating, the I^2R loss is proportional to $(100 + X)^2$ where X is the percent boost. For example, with a 15 percent buck and boost synchronous booster rotary converter, the conditions are as follows:—

Direct-Current. Output in Percent		Percent Booster Arm. I^2R Loss
Current	Voltage	
100	85	72
100	100	100
100	115	132.5

Further, owing to the necessity for a definite mechanical relation between the stationary armature windings of the booster and the field structure of the converter, and the difficulty in obtaining this relation after calculation, in order that the proper electrical

relations should exist between the electromotive forces of the booster and converter, it was soon found impossible to use a stationary frame of standard construction. The frame was accordingly constructed so that it could be rotated and the armature winding of the booster thereby placed in the position of maximum efficiency as determined by its effect upon the continuous voltage. This is the type of shifting ordinarily employed on one machine of a frequency changer set.

In the converter proper, modifications were necessary:—

1—To prevent magnetic saturation at the highest voltage.
2—To insure sufficient main field strength for maintaining unity power-factor at all loads and voltages.
3—To provide ample section of armature conductor to take care of the increased I^2R loss when the booster is operating, without excessive heating.
4—To maintain satisfactory commutation under loading conditions in which the armature reaction which must be compensated for does not vary proportionally to the direct-current output.

It is therefore obvious that such far-reaching modifications were required in the construction of the simple alternating-current generator and of the simple rotary converter, when combined, in order to insure a satisfactory synchronous booster converter unit, that it became rather far fetched to call the combination an application of old standards. It may be questioned whether it would not in fact have shown greater foresight to have forgotten or ignored the relationship to older apparatus except in fundamental principles, and to have standardized as quickly as possible the booster rotary converter as an independent piece of electrical apparatus.

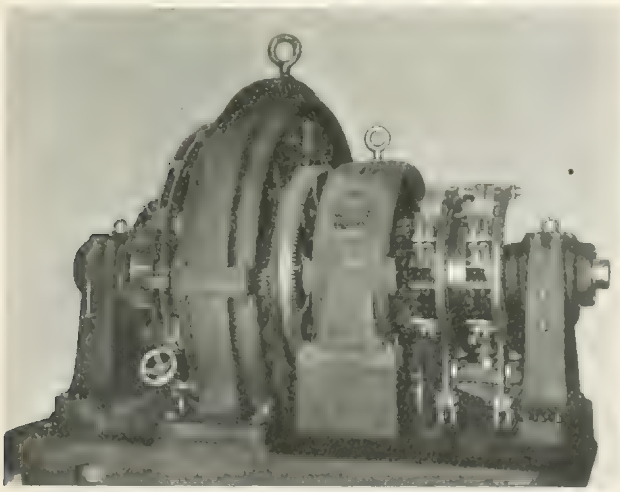


FIG. 2—ONE OF THE EARLY BOOSTER ROTARY CONVERTERS

A 500 kw, 250 volt, 25 cycle, three-phase, ten percent buck and boost machine built for the Carnegie Steel Company in 1906-7. Note old bar and end-connected type of booster armature winding.

REVOLVING ARMATURE BOOSTER ROTARY CONVERTERS

The remaining discussion will apply particularly to the type of booster rotary converter first referred to, which is the one now most generally built; that is, the one in which both booster and converter have revolving armatures. It has been mentioned that it is important that the field and armature windings of the booster be placed in proper mechanical relation to the windings of the converter, in order that the voltage generated by the booster shall be in phase with the voltage applied to the collector rings, so that for a given booster field excitation the vector sum of these two voltages shall be either a maximum or a minimum, depending upon the direction of the excitation.

FIG. 3—TYPE OF CONVERTER USED IN EARLY BOOSTER [illegible] CONSTRUCTION

Showing method of combining cross-connection and commutator necks on the converter proper.

The practice for a long time was to assemble the two armatures on the common shaft without special regard to the relative mechanical positions of their windings; then, the proper relation between the electromotive forces generated was obtained by arranging the field frame of the booster so that it could be rotated, as shown in Fig. 4. The field frame of the booster is here shown carried from the frame of the converter. It was planned that when the unit should be tested the booster frame would be shifted by means of the slotted hole provided for the holding on bolts, to the position in which the voltage generated in the booster winding had the greatest effect upon the continuous terminal voltage of the converter.

It was later found, as a refinement in the art, that the rotating armature windings of the booster and converter could be accurately laid out and assembled in the unit so as to secure the desired voltage relations and that the field frame shifting feature could be eliminated. This development has reduced expense and made a neater appearance and has been found especially desirable in the case of large synchronous booster converters, such as that shown in Fig. 5, where the frames are separate and the difficulties in the way of securing rigidity when using an adjustable frame are very considerable.

Fig. 6 shows the winding and connections development of a two-phase, 14 pole booster converter hav-

ing 112 slots in the booster and 168 slots in the converter armature. The windings are laid out so that, with the field poles in line when looking at the end of the unit and the armatures keyed on the shaft so as to give the relation shown in Fig. 6, the instantaneous voltage generated in the booster windings between the

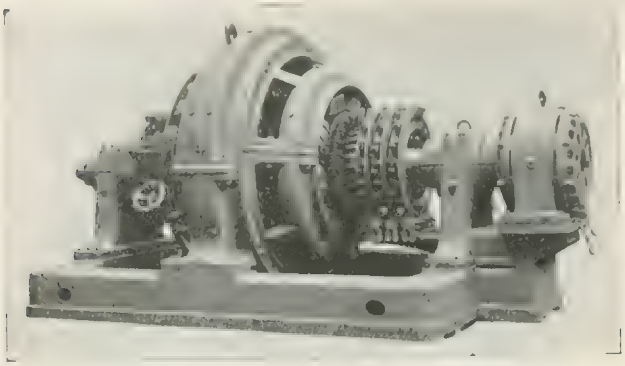


FIG. 4—EARLY CONSTRUCTION IN BOOSTER CONVERTERS
Showing method of adjusting the booster frame circumferentially to obtain the proper electromotive force relations between the booster and converter proper.

ring A_1 and its taps to the converter winding and the ring A_2 and its taps to the converter winding reach a maximum at the same time that the counter electromotive force generated in the converter winding between the same taps reaches its maximum. It is customary to make the field poles on the booster and the converter line up when looking at the end of the unit; and, uniform material and good workmanship being assumed in the construction, exact results are obtained from this method of construction.

EFFECT UPON THE DESIGN OF THE CONVERTER PROPER

The influence of the combination with the synchronous booster upon the design of the converter proper has been briefly outlined, but it is perhaps advisable to explain this influence more in detail. It has been stated that in the converter itself modifications in design are necessary:—

1—To prevent magnetic saturation at the highest voltage.
2—To insure sufficient main field strength for maintaining unity power-factor at all loads and voltages.
3—To provide ample section of armature conductor to take care of the increased I^2R loss without excessive heating when the booster is operating.
4—To maintain satisfactory commutation under loading conditions in which the armature reaction which must be compensated for does not vary proportionally to the direct-current output.

The first requirement has been taken care of simply by the addition of more steel in all parts of the magnetic circuit, making a heavier and more costly machine.

The second requirement has usually been taken care of by the addition of a large amount of copper to the main shunt field. There is a great variation in the main field strength required to maintain 100 percent power-factor over the entire range of load conditions, from the no-load minimum voltage condition to the full-load maximum voltage condition. The changes in field strength required are due to:—

a—Differences in saturation with change in voltage.
b—Differences in the reactive effect of the load current.

The difference between the extreme conditions amounts to more than 100 percent in some cases. Fig. 7 shows the change in magnetic saturation and the increase due to load variation at a constant voltage for the same converter. Item *a* is partially taken care of automatically by the increased field current due to the greater field voltage. It can more exactly be compensated for by the addition of an auxiliary field to the main poles, excited proportionally to the booster field excitation in direction and strength. The bend in the saturation curve is thus approximately compensated for. The effect of *b* is not influenced by this auxiliary field, however, and it can only be compensated for by a series field on the main poles. Owing to the heavy current to be carried by such a field, the lack of room and other mechanical disadvantages have so far precluded its use.

The third requirement is taken care of simply by the use of a larger armature conductor, resulting in a larger and costlier machine. The effect of the booster upon the armature I^2R loss was discussed in an article by the author in the February, 1913, issue of the JOURNAL and will not be reviewed at this time.

The fourth requirement (to maintain good commutation over the entire range of load and voltage) is one which has caused considerable scheming and calculation to satisfy. Commutation is fundamentally

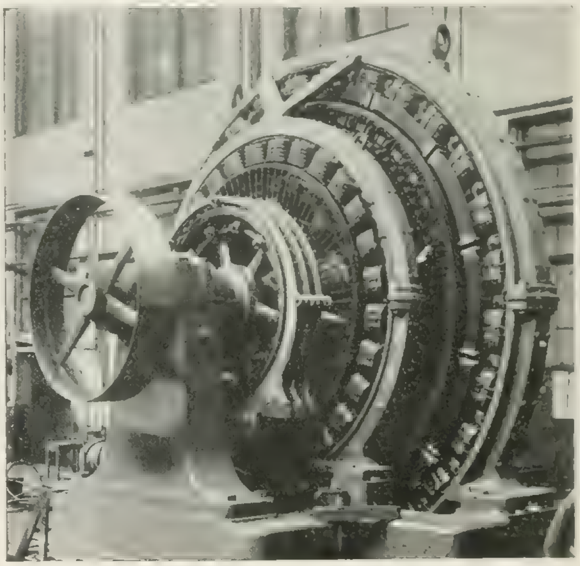


FIG. 5—LATER CONSTRUCTION OF BOOSTER FRAME
Showing greater rigidity possible as compared to construction in Fig. 4 after design methods had made circumferential adjustment no longer necessary.

dependent upon the dimensions of the machine and the amount of current to be commutated. It is customary from these quantities to calculate directly the flux required by the short-circuited conductors to commutate this current or to calculate a voltage-"reactance voltage," "short-circuit voltage," "inherent voltage under the brush," or whatever the individual engineer chooses to call it,—which would exist under the brush and produce sparking and burning were this

voltage not killed by means of an active flux. In the non-commutating pole machine this commutating flux was obtained by shifting the brushes until they short-circuited conductors located in the necessary reversing field. In the commutating pole machine this flux is injected into the armature by the magneto-motive force of the ampere turns on the commutating pole. There is, therefore, no great inherent difference between the commutating requirements of an armature when in a non-commutating pole or in a commutating pole machine. It is only much easier in the latter than in the former to obtain the desired shape of reversing field under the varying conditions of load.

The detrimental effect of introducing commutating poles was overestimated. The great benefits have come about through the partial compensation for armature reaction, the greater magnetic reluctance in the path of flux due to armature reaction at the main pole tips and the more suitably shaped field form. These latter two points are due

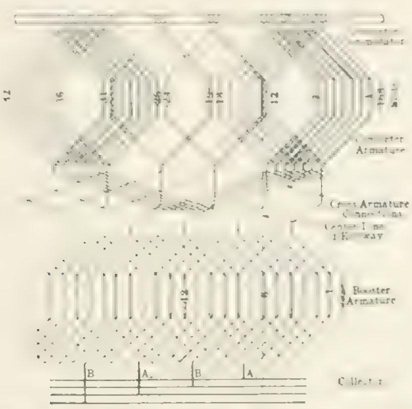


FIG. 6—DEVELOPMENT OF BOOSTER AND CONVERTER ARMATURE WINDINGS AND CONNECTIONS

Center line of slot No. 6 coincides with center line of slot No. 12 of converter. Armatures are keyed in this position. The windings are so laid out that the center line of the group of coils containing the tap coil from the collector ring A_1 and lying in slots *1* and *8* of the booster, lies between the converter armature coils in slots *1—12* and *13—24*.

to the smaller ratio of pole face to pole pitch, while the last is also due to the actual superposition of the flux from the commutating pole. It is possible that the improvement of the modern rotary converter, the 60 cycle converter especially, over some of those first built has been due to the smaller ratio of pole face to pole pitch employed more than to any other single factor. In those machines this ratio was made large so as to reduce the magnetic densities and save copper. The earliest theory as given in text books of the day was to the effect that there was no armature reaction. Owing to the high efficiences and the very small current per pole there was no evidence of armature reaction under normal conditions. The very slightest shift of the brushes was necessary. This was due to the exceedingly steep field form at the neutral point resulting from the high ratio of pole face to pole pitch, against which ratio there seemed to be no opposition in theory or practice. The armature reaction was, of course, present at all times. It asserted itself, however, only under surging or hunting conditions when it, together with the steep field form, which permitted excessive voltage under the brush with a very slight angular displacement of the armature, rendered a machine poorly equipped with dampers very sensitive to flashover. In later 60 cycle converters the magnetic densities were greater and, in addition to many other improvements, a flatter commutating field was provided. The further addition of the commutating pole, as before mentioned made it possible to improve the shape of that field and to prevent its position from being shifted by the armature reaction which with the increased current output per pole of the later machines became a noticeable factor even under steady load conditions.

In order that the commutating pole should not be a disturbing element under unsteady load conditions, the damper winding was given special consideration in the design. The chief feature is that the heavy end rings of the cage winding are made continuous

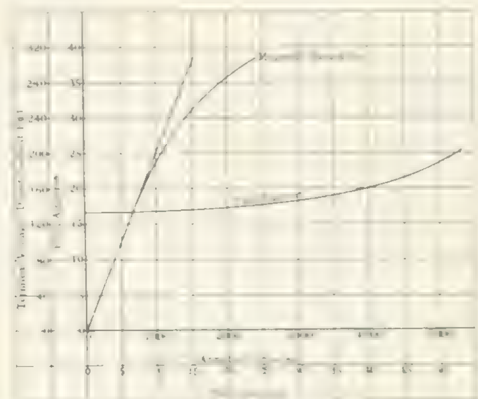


FIG. 7—CHARACTERISTIC [illegible] BOOSTER ROTARY CONVERTER

Showing increase in main field current with increase in armature amperes without buck or boost, and at a constant voltage and variation in magnetic saturation from a straight line without buck or boost.

so that in connection with the heavy bars at the sides of the main poles, a low resistance circuit is established surrounding the commutating poles. It will be well to consider briefly some of the effects of this arrangement:

1—Under steady load conditions the variations of flux in the commutating pole due to variations in armature counter magneto-motive force and variations in the reluctance of the commutating pole air gap are partially damped out.

2—With unsteady load but steady supply voltage and frequency, any change in direct-current load is followed instantaneously by a corresponding change in the alternating-current input unless the rotating element has a very appreciable flywheel effect.

It has been said that the short-circuit path tends to produce a lag in the commutating flux produced by the varying current in the commutating pole field winding. There is no lag, however, in the varying ampere-turns to compensate for the variations of armature reaction due to load changes. These are in a state of balance.

3—With unsteady load and varying supply voltage and frequency, owing to flywheel effect, a change in direct-current load is not necessarily followed instantaneously by a corresponding change in the alternating-current input. The effect of the short-circuit path will be, however, to dampen out the flux in either direction due to an instantaneous unbalance between armature ampere-turns and commutating pole ampere-turns.

4—In addition to maintaining more uniform conditions at the point of commutation in the manner described in *1*, *2* and *3* above, these continuous end rings, by lowering the resistance in the path of the damping current generated in the main pole slot bars, greatly improve the efficiency of the damper as a whole tending to prevent the initial hunting which is the cause of the unbalance mentioned in *3*. This method of construction is, therefore, advantageous under all conditions of operation.

The total resultant armature reaction in a rotary converter integrated about the periphery is the difference between the alternating-current reaction and the direct-current reaction and is proportional to the efficiency of the converter. This is brought out by the following example:—

Assume a six-phase, two-pole, 600 volt, 215 kw rotary converter with 95 percent efficiency and 90 commutator bars. There are then 180 conductors or 90 turns on the armature.

As a synchronous motor, the magneto-motive force per pair of poles equals $3/2\ \sqrt{2}\times IT$ where I equals the effective current per phase and T equals the number of turns per pair of poles per phase. Then in this case, the magneto-motive force equals $3/2\ \sqrt{2}\times\frac{177.5}{2}\times 90 = 16\,900$. As a direct-current generator, the magneto-motive force per pair of poles equals the current output per pair of poles $\times$ the number of commutator bars per pole $= 358.5\times\frac{90}{2} = 16\,100$. The resultant magneto-motive force equals $16\,900 - 16\,100 = 800$ ampere-turns. 16 100 divided by 16 900 equals 95 percent, the assumed efficiency.

The way this reaction varies about the periphery under steady load conditions was explained by Mr. B.

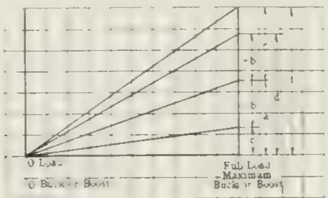


FIG. 8—DIAGRAM OF REACTION UNDER CONVERTER BRUSH AND CORRESPONDING REQUIRED AMPERE-TURNS ON THE COMMUTATING POLE

G. Lamme and Mr. F. D. Newbury in the December, 1910, issue of the JOURNAL. Without reviewing this matter, it remains that the reaction under the brushes is a direct-current reaction and that, although it is a variable quantity, between the limits of seven and 20 percent in the simple converter, it averages somewhere between 12 and 16 percent of the armature ampere-turns. It is less in a chorded winding than in a pitch winding. An equal magnetomotive force must be supplied by the commutating pole before any flux can pass. Adding to this the amount of ampere-turns necessary to produce an active commutating flux the total on the commutating pole will be from 25 to 40 percent of the armature ampere-turns. The addition of the synchronous booster requires a further investigation of and correction for armature reaction.

Let the average magnetomotive force of the simple converter under the commutating pole be *a* percent of the armature ampere-turns, as shown in Fig. 8. When the booster field is excited, so that the alternating voltage generated "bucks" the impressed voltage, the alternating-current machine acts as a motor and is capable of delivering mechanical power. When the field is excited so that the alternating voltage generated "boosts" the impressed voltage, the machine acts as a generator and mechanical power must be delivered to it. This alternating-current generator or motor being directly connected to the simple rotary converter, it is obvious that mechanical power may be delivered to or obtained from the rotary converter. When obtaining power mechanically from the rotary converter, the alternating-current generator, by boosting the impressed voltage, causes the direct voltage delivered by the rotary converter commutator to increase by the same percentage, owing to the approximately constant ratio existing in the simple rotary converter between the alternating voltage at the taps and the direct voltage at the commutator. When delivering power mechanically to the rotary converter, the alternating-current motor lowers the direct voltage delivered by the rotary converter in a similar manner.

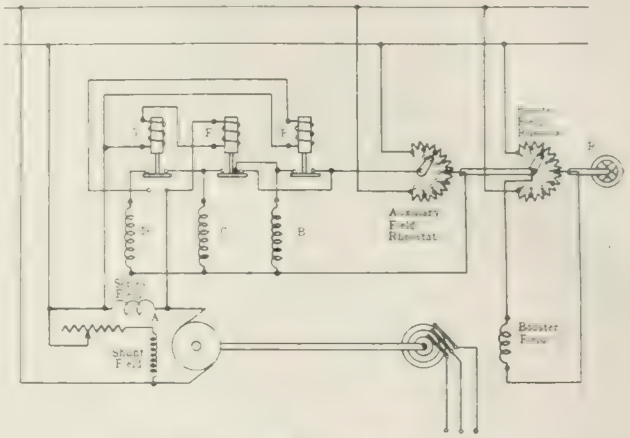


FIG. 9—DIAGRAM OF FIELD CONNECTIONS

The position of the rheostat handle determines the strength of the auxiliary field relative to the amount of buck or boost. The relays, *E*, *F* and *G*, regulate its strength in proportion to the amount of load being actuated selectively in the order mentioned.

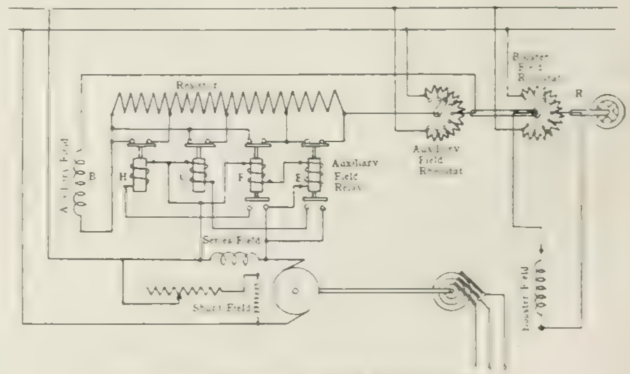


FIG. 10—DIAGRAM OF FIELD CONNECTIONS

With this scheme, the strength of the auxiliary field is regulated in proportion to the amount of load by having the relays, *E*, *F*, *G* and *H*, cut out a series resistor in sections, being actuated selectively by the drop across the series field, in the order mentioned.

The additional current which flows in the simple rotary converter armature winding when the field of the alternating-current generator or motor is excited produces an armature reaction *b*, Fig. 8, under the commutating pole. Since this additional current is directly proportional to the voltage generated by the

alternating-current generator or motor, the reaction b is at full load the same in percent as the "buck" or "boost." When the alternating-current machine is acting as a motor and is lowering the direct voltage, the rotary converter, being driven by the motor, delivers some of its direct current as a direct-current generator, and the additional armature reaction b is added to the simple armature reaction a, giving a total of d. When the alternating-current machine is acting as a generator and is raising the direct voltage, the rotary converter in addition to delivering direct current is acting as a synchronous motor and supplying power mechanically to the alternating-current machine. The additional armature reaction is, therefore, a motor reaction $-b$ and subtracts from the simple armature reaction a, giving a remainder c.

In the simple rotary converter, the commutation is effected, as is well known, by a strap winding on the commutating pole with ampere-turns proportional to the direct-current output obtained by connecting the winding in series with one of the converter terminals. As mentioned, the armature reaction a is proportional to the direct-current output. The commutating pole flux required to commutate the current is also obviously proportional to the current. The ampere-turns e to produce this flux, assuming no leakage or saturation, will then be proportional to the current. Hence, the total ampere-turns f on the commutating pole in percent of armature ampere-turns will be directly proportional to the direct-current output. This is also true for the synchronous booster rotary converter when the alternating-current generator or motor is not excited. And under all conditions of buck or boost the ampere-turns e, required to produce a commutating voltage in the conductors short-circuited by the brush, are proportional to the current; but, as has been stated above, the resulting average armature reaction varies, depending upon the "buck" or "boost." For the different conditions of load, therefore, the ampere-turns on the commutating pole should be as follows:—

Voltage Condition		Full Buck	Normal	Full Boost
Ampere turns	**(No load)**	0	0	0
required	(Full load)	$d + e$	$a + e$	$c + e$

The additional ampere-turns b or $-b$ are supplied by means of a fine wire winding usually located above the series winding, which is of course designed with $(a + e)$ ampere-turns. Since the excitation of this fine wire winding must be proportional to the additional direct current or alternating current flowing in the converter armature winding when the booster is excited, it is taken care of in the following manner:—

The additional current is directly proportional to the booster voltage, and therefore approximately to its excitation, and it is directly proportional to the direct current flowing from the main terminals of the converter. Accordingly, a reversing rheostat is placed [illegible] commutating pole field winding" and is mechanically connected to the booster field rheostat so that any change in the latter produces a corresponding change

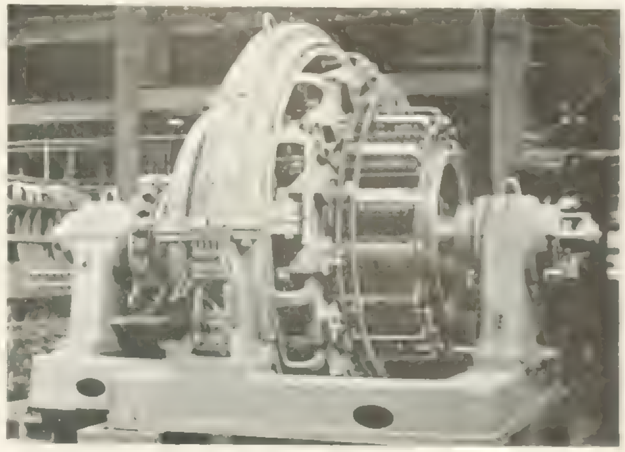


FIG. 11—[illegible]

in the former. Further, this auxiliary commutating pole field winding is divided into a plurality of parallel circuits made or broken by an equal number of relay switches operating proportionally to the direct current flowing in the commutating pole series field winding. In Fig. 9, A is the series field, B, C and D the three sections of the commutating pole auxiliary field and E, F and G the controlling relay switches. D is the reversing rheostat handle on the same shaft with the booster field rheostat arm. Fig. 10 shows a second method of control which has been employed. In it the auxiliary field is in one section, but a number of resistances are connected in series by means of relay switches so as to vary the auxiliary field current with approximate proportionality to the main current. The relay switches are the same in either method, but in the former the series resistances are unnecessary and some complication is avoided. Figs. 11 and 12

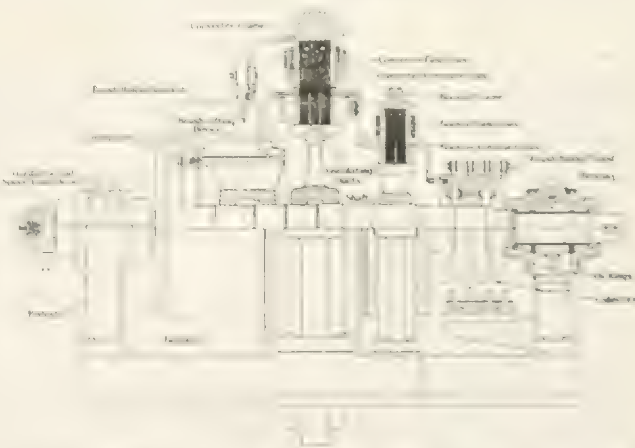


FIG. 12—SECTIONAL VIEW OF A CONVERTER SUCH AS SHOWN IN FIG. 11

show a 1 500 kilowatt, two-phase, 60 cycle, 270 volt, 450 r.p.m., 15 percent booster rotary converter, built in accordance with the principles of design outlined in this article.

Balanced Hoisting Systems

Wilfred Sykes

THE FOLLOWING article, in continuance of a discussion by the author in the March issue of the Journal, *which covered the mathematics of simple drum and conical hoists, treats of balancing systems, which employ the effect of flywheels in their operation. The Ilgner and the converter hoisting systems are described and compared together with the service conditions to which each is most adaptable from the standpoints of operation and cost.*

PRACTICALLY all balancing systems of hoisting utilize a flywheel, the speed of which is varied so that it gives up or absorbs energy according to the demands of the system. A storage battery may also be used for the same purpose and under certain circumstances it may be more economical than a flywheel, as the losses with the latter are constant and independent of the load, while the storage battery losses only occur when the battery is being used. The main requirements of a balancing system are that it should be capable of preventing the peaks from coming on generating stations, it should be automatic in action and the losses connected with it should be as low as possible.

The first practical system to be introduced was that proposed by Mr. Carl Ilgner, which, in various

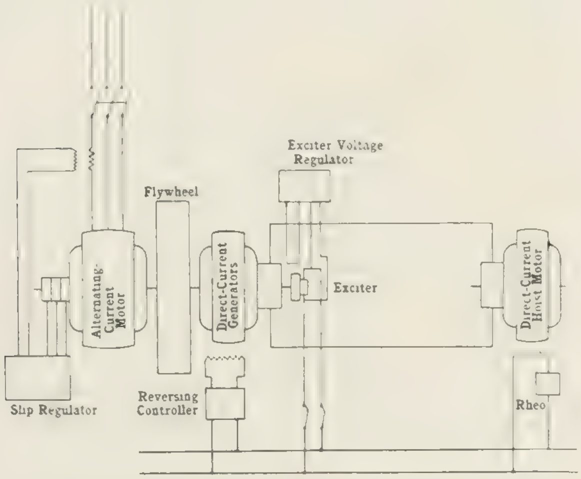


FIG. 1—COMPLETE DIAGRAM OF CONNECTIONS FOR ILGNER HOISTING SYSTEM

modified forms, has been very widely adopted for all classes of heavy work where greatly fluctuating loads have been taken care of. Probably 90 percent of the equalizing systems installed are based on this principle. It will be noted that the whole of the power used by the hoist is transformed and also that there are no rheostatic losses at starting. The Ilgner system as arranged for use with alternating current consists of an alternating-current induction motor with a wound rotor, coupled to a direct-current generator, which, in turn, feeds a direct-current shunt-wound hoist motor. Coupled to the motor-generator is a suitable flywheel designed to take care of the peak loads. The fields of the hoist motor and of the direct-current generator are excited separately by a small exciter coupled to the motor-generator set, means being provided for automatically maintaining its voltage constant when the speed of the set varies. The speed of the motor-generator set is controlled by means of an automatic slip regulator operated by the line current. The scheme of operation is as follows:—

At the beginning of a hoist cycle the flywheel is running at full speed, all resistance being cut out of the motor rotor. In order to start the hoist, the generator is gradually excited in the proper way to obtain the desired direction of rotation. As the speed of the hoist motor with constant field excitation is practically proportional to the voltage of the generator, when the latter is increased the speed of the hoist also increases until with full voltage the maximum speed is obtained. The only rheostatic losses at starting are those in the regulator controlling the generator field, which are negligible.

When the load on the induction motor exceeds the mean value for which the slip regulator is set, resistance is automatically introduced into the rotor so as to cause a reduction of speed, thus enabling the flywheel to give out a portion of the energy stored in it and thereby assisting the motor to drive the generator. The speed is automatically reduced so as to maintain constant input to the three-phase motor until the flywheel has given out all the energy required in excess of the mean value. When the load falls below this mean value the regulator cuts out the resistance in the rotor causing the set to increase in speed, thus storing energy in the flywheel and keeping the demand on the line constant.

The use of resistance in the rotor of the three-phase motor introduces a certain loss which will average half the slip between full and minimum speeds but, as a rule, this loss is small compared with the output of the plant. The question as to the most economical slip value to adopt is a very complicated one, depending as it does upon the first cost of the flywheel, the running losses, the time the plant is in service, etc. It will be seen that should the plant run for a considerable period without load it might be advisable to allow a fairly large slip and to use a light flywheel so that the constant loss would be small. On the other hand, if the plant runs continuously, the intervals between trips being short, the slip regulator losses will bear a totally different relation to the input, and under such circumstances a relatively small slip and a heavy flywheel might be the most economical arrangement. It has been found in practice that a slip of 12 to 15 percent is about the most economical value, although in some plants a slip as high as 20 per cent is provided for. Since the energy stored in the flywheel is proportional to the square of the velocity, it will be seen that

by increasing the slip a proportional increase is not obtained in the output. Thus with a 15 percent slip the energy available will be 28 percent of the total in the flywheel. With 20 percent slip the amount available is only increased to 36 percent.

The general connections of a hoisting plant on the Ilgner system with alternating-current supply are given in Fig. 1, and from the description given the functions of the various parts will easily be followed.

The size of the flywheel may readily be obtained from the load diagram which has already been calculated.* It is necessary, first of all, to determine the

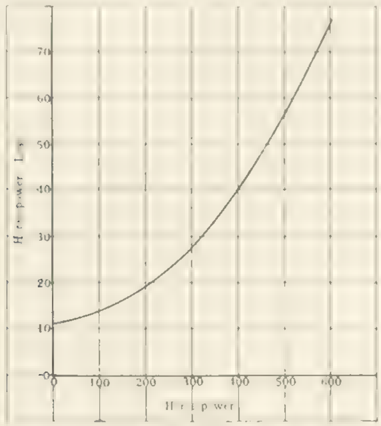


FIG. 2—CURVE SHOWING VARIATION IN HOIST MOTOR LOSSES WITH VARIATION IN LOAD

total input to the generator which must be furnished by the flywheel and driving motor. To do this, the most convenient method is to take the losses of the hoist motor and generator and add them to the loads already mentioned. Figs. 2 and 3 show approximate loss curves for the hoist motor and generator, and from these curves the values in Table I have been derived:

These figures are not exactly correct, as it is assumed that the iron loss, windage and friction is the same

TABLE I—HORSE-POWER VALUES FOR MOTOR AND GENERATOR DURING A HOISTING CYCLE.

	Motor output	Motor input	General input	
Accelerating	555	618	691	680 average
	540	601	669	
Constant	300	328	348	
Speed	183	201	209	
Retarding	-57	-46	-46	-53 average
	-71	-60	-50	

during the starting and stopping periods as when running at full speed, which is not the case, but the error introduced is very small. For convenience, the average horse-power values during the accelerating and retarding periods are taken, as this simplifies the calculation. The other losses will be included later.

We now have a load diagram of the input to the generator as given in Fig. 4. The function of the flywheel is to supply the power required above the average input to the generator, the total input to which is:—

Accelerating period, [illegible]

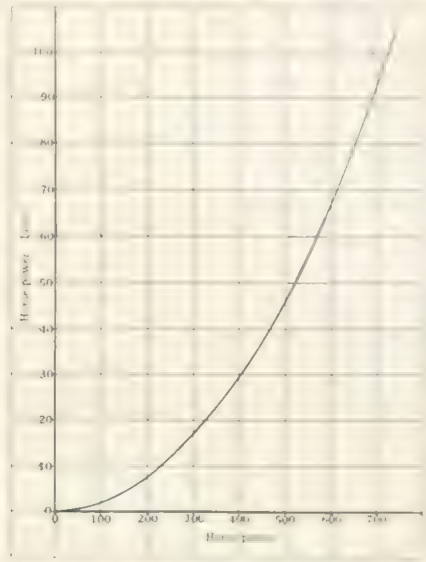
Constant speed, [illegible]

Total [illegible]

[illegible]

Net input to generator...... = 14 275 hp-seconds.

Average input during hoist cycle, $\frac{14\,275}{75}$ = 190 hp.



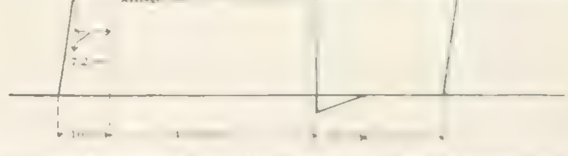
[illegible]

Referring to Fig. 4, it will be seen that the area above the average of 228 hp corresponds to the following:—

Accelerating period $\frac{680-190}{2}\times 7.2 =$ 1 760 hp-seconds.

Constant speed period [illegible]

Total [illegible]



[illegible] ERATOR INPUT DURING THE HOISTING CYCLE

This output must be carried by the flywheel if the input is to be completely equalized, and it will be returned to the wheel during the period that the input is less than the average.

The weight of the flywheel depends upon the type and the peripheral speed:—

Where V_1 = velocity in feet per second at radius of gyration, full speed.

V_2 = velocity in feet per second at radius of gyration, minimum speed.

*See article by the author in the JOURNAL for Mar., 1914, p. 144.

If a solid plate wheel is used, the radius of gyration is 0.707 of the wheel radius. It is common practice to run plate wheels at a peripheral speed of 20 000 feet per minute, although occasionally higher speeds are used. If the peripheral velocity is taken as above, we have,—

$$V = \frac{20\,000 \times 0.707}{60} = 236 \text{ ft. per sec}$$

A speed drop of 15 percent is usual, so,—

$$V = 236 \times 0.85 = 200 \text{ ft per sec}$$

The weight of the flywheel will be,—

$$\frac{5\,300 \times 550 \times 64.4}{236^2 - 200^2} = 12\,050 \text{ lbs.}$$

The motor for driving the set may carry the average load plus the losses that have been so far neglected. It is estimated that they will be as follows:

Windage and friction and iron loss of generator	16 hp
Flywheel windage and friction	15 hp
Excitation of hoist motor and generator	18 hp
Total	49 hp

In addition, there is the loss in the slip regulator, which, with a slip of 15 percent, if an induction motor is used, will be 7.5 percent of the total output, or approximately 8.1 percent of the average input of 190

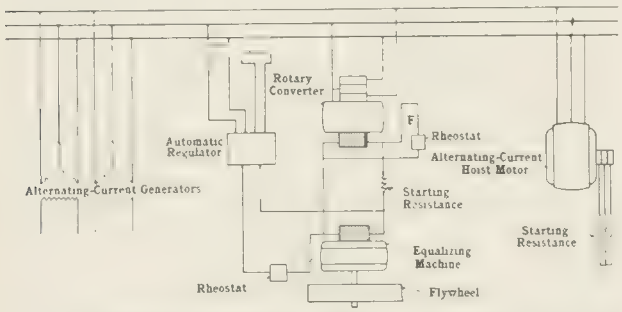


FIG. 5—CONNECTION DIAGRAM SHOWING APPARATUS AND ITS ARRANGEMENT IN THE CONVERTER SYSTEM OF HOISTING

hp, plus the above losses. This will be approximately say, 21 hp. The total load on the driving motor will be:—

Average input to generator from diagram	190 hp
Losses not included in average input	70 hp
Input, or rating, of driving motor	260 hp

If the flywheel set is driven by a direct-current motor, the speed regulation will be obtained by varying the shunt field so that the loss will be negligible and the capacity required will be reduced by the amount of the slip regulator loss. The overall efficiency of the equipment may be readily determined. The total net work is,—

$5\,000 \text{ lbs.} \times 1\,000 \text{ ft.} = 5\,000\,000 \text{ ft-lbs.}$

The motor output is 260 hp for 75 seconds and, allowing an efficiency of 91 percent for the induction motor, this is,—

$$\frac{260}{0.91} \times 75 \times 550 = 11\,700\,000 \text{ ft lbs.}$$

$$\text{Overall efficiency} = \frac{5\,000\,000 \times 100}{11\,700\,000} = 42.7 \text{ percent.}$$

The above overall efficiency is very low, due to the high accelerating peaks, in relation to the average load; but this example will serve to illustrate the method by which the size of apparatus required can be determined.

THE CONVERTER SYSTEM

Another system of importance, suitable for alternating current, is that known as the converter system, the principle of which is altogether different from that of the Ilgner system. The connections of this system as applied to three-phase hoisting plants are given in Fig. 5. The hoist motor in this case is of the induction type with a wound rotor, being started by means of a rheostat. In order to equalize the demand on the line, the equalizing system is connected in parallel with the generator station. It consists of a rotary converter and a direct-current machine to which is coupled a suitable flywheel. The operation of the arrangement is as follows:—

The rotary converter acts only as a connecting link between the alternating-current system and the equalizing set, which consists of a shunt-wound direct-current machine and the flywheel. The field of this machine is controlled by a regulator, operated by the main line current. At the beginning of a trip the flywheel is running at full speed, and when the load exceeds the mean value, the regulator automatically strengthens the field of the equalizing machine so that it acts as a generator driven by the flywheel. The amount of energy given to the rotary converter and thence to the line will depend on the requirements in excess of the mean, as the regulator will continue to cut out resistance so long as there is any tendency for the line current to increase above the mean.

When the demand drops below the average the regulator will weaken the field, causing the machine to run as a motor, which, taking energy from the line through the rotary converter, speeds up the flywheel, the rate at which resistance is introduced to the field depending on the difference between the demand on the line and the mean load. In this way energy is stored in the flywheel and the line load is kept constant. The rotary converter changes either direct current to alternating current or vice versa, depending on whether the flywheel set is giving up or absorbing energy. It will be seen that the speed variation is obtained in field regulation, so that the loss is negligible, whereas with the Ilgner system it is from 7.5 percent to 10 percent of the input to the driving motor. This is a very important feature in equalizing systems with direct-current machines, as a much greater slip can be economically obtained, it being the usual practice to allow from 20 percent to 25 percent, and consequently the flywheels can be comparatively light. The machines of the equalizing set need only to be large enough to deal with the loads which exceed the mean value, and under ordinary circumstances the capacity will not be more than about half that of a motor-generator set for the same duty. The equalizing equipment is quite independent of the hoisting motor, so that it may be out of service and the only difference will be that the peak

loads will come on the line, but with the Ilgner system the hoist is dependent on the motor-generator.

The main difference between the two systems is that the Ilgner method provides for starting the hoist motor by voltage control without any rheostatic losses, while the converter arrangement makes no provision for doing so. When considering the economy of both systems this difference must be considered, as starting losses are often a large proportion of the total input. The question of starting is one of the important ones with large hoists, and on this account the Ilgner system is preferred for heavy work. Motor-generator sets without flywheels have been installed in a number of instances for the sole purpose of obtaining a simple and efficient method of starting. With small hoists the starting devices are not difficult to design and this feature, together with the fact that one converter equalizing equipment may be used for a number of hoists, gives this arrangement an advantage over the Ilgner system, especially as the cost is somewhat lower. It will be seen that the converter equalizing equipment is not necessarily located near the hoist, which is an important feature when it is inside a mine. In this case a high tension system may be used, transformers being placed between the converter and the line, and the equalizer set being in the power station or substation on the surface.

When the power supply is direct current the speed of the driving motor of the Ilgner motor-generator set is varied by shunt regulation and the slip may be made between 20 percent and 25 percent. With the second arrangement the converter is omitted, the equalizing machine being connected directly across the line.

The question as to the desirability of an equalizing equipment for any particular installation depends entirely on local conditions. The Ilgner system has been very widely used and has undoubtedly solved the problem of handling large loads at high speeds, but it is only by making a careful analysis of the conditions that intelligent recommendations can be made.

Practical Speed Adjustment of Alternating-Current Mill Motors

WITH METHOD OF ADAPTING THE SAME PRINCIPLE TO MINE FANS

G. E. Stoltz

Due to the fact that the material rolled in steel mills varies in size and shape, speed adjustment becomes a necessity. When the output of the mill can be confined to material varying little in section, a single-speed prime mover is sufficient. In order, however, to handle different sizes, give some material better finish than others, or secure greater accuracy in the finished product of some orders than others, speed adjustment is required. Large sizes cannot be rolled at too high a speed, as considerable trouble is encountered when entering the metal in the rolls. If the speed is too slow, the tonnage is reduced, the metal cools too quickly, and it is not thrown a sufficient distance from the stand to pass it conveniently from one stand to another.

INDUCTION MOTORS

Rheostatic Control—Due to the simplicity of rheostatic control it is by far the most desirable, but it is uneconomical when the range of speeds required is great. In addition to this objection the speed of the motor controlled in this manner varies with load from full-load speed, which is determined by the amount of resistance in the secondary, to approximately synchronous speed when the mill is running light. An installation of this type, when used in conjunction with a flywheel, will operate at practically constant speed, so long as the mill is kept fairly well filled with metal, but delays are frequent, at which times the mill comes up to a speed near synchronism. When operations are resumed, difficulty is encountered in entering the metal in the rolls, due to the high speed. With this variation in speed, some pieces are rolled with greater dispatch than others, resulting in a variation in temperature of the finished product. Under such conditions, it is impossible to obtain steel of uniform gauge.

Multi-Speed Motors—This type of motor usually consists of two separate windings on the primary and secondary or, where a two to one speed ratio is desired, the winding is reconnected, being used in parallel for the high speed and in series for the low speed. The number of speeds to be obtained in this manner is entirely dependent upon the number of windings placed on the motor. With several windings, considerable slot space is necessary. Since only a portion of this space is in active use at any one time, the motor performance inherently becomes poor and, where a large number of induction motors are used, it is undesirable to install machines which aid in reducing the power-factor unnecessarily. In addition to this, the complexity of the control and the high cost of motors with several windings has limited the multi-speed motor to practically two speeds. These two speeds can be varied somewhat by rheostatic control, so that in many cases this type of motor is most satisfactory.

Cascade Motors—The synchronous speed of an induction motor is equivalent to the number of alternations per minute of the line to which it is connected, divided by its total number of poles. If the secondary circuit of one machine is connected to

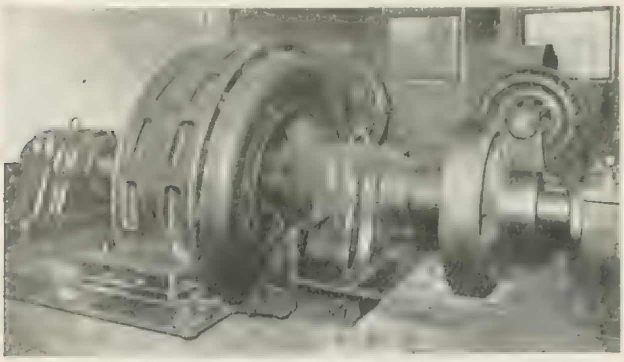


FIG. 1—MAIN ROLLING MILL MOTOR
Rotary converter and motor-generator in background

the primary of another, the frequency of the latter is supplied by the slip of the former. By placing both machines on the same shaft, or otherwise causing them to rotate at the same speed, a new synchronous speed is obtained. This now becomes the number of alternations of the primary circuit divided by the sum of the number of poles in both machines. Or, if the two machines are connected differentially, that is, one of the phases of the primary on the second motor is reversed, the resulting speed will correspond to the difference of the number of poles. Thus, the number of distinct synchronous speeds depends upon the number of motors connected in tandem. However, practical limits restrict the number of machines to two. Operating each machine independently provides two additional speeds.

The performance of motors connected in cascade is similar to that of a single motor. The slip increases with the torque. Exciting current and impedance losses of both machines, as well as windage and friction, must come through the primary of the first motor.

Due to poor performance, and since the combination is ultimately the equivalent of a multi-speed motor, very few installations have been made in this country. Large initial cost and the complexity of control also have been quite instrumental in causing operators to abandon this method.

POLYPHASE COMMUTATOR MOTOR

The characteristics of this machine are similar to those of the well known direct-current motor. In the latter motor two voltages are present, viz:—rotation voltage, which is the counter electromotive force generated by the armature turns cutting the field lines of force; and the ohmic drop, due to the resistance of the conductors carrying the current. Due to the alternating currents, an additional voltage is developed in the windings of the alternating-current commutator machines. This may be termed the reactance voltage. The first two voltages mentioned above are in phase with the current but, with the entrance of a reactance voltage, phase displacements and commutating troubles are introduced. Unfortunately, the inherent characteristics are such that good commutation is obtained at the expense of poor power-factor, and vice versa.

A number of methods have been tried to obtain good commutation and a reasonable power-factor simultaneously under varying load conditions, the most successful being obtained by placing a compensating winding on the stator designed to neutralize the reactance voltage of the rotor. The distribution of this winding introduces considerable complication, and makes the windings and connections, as a whole, very intricate.

Several installations have been made in Europe, using the polyphase commutator motor as a part of the outfit for controlling the speed of alternating-current rolling mill motors, but without marked success, even after considerable time and money have been spent on the machines after installation. To date, no installation has been made in this country which successfully meets the severe requirements of this application and, considering the time the Europeans have spent in trying to adapt this apparatus to rolling mill service, its future in this field is not promising.

ROTARY CONVERTER AND MOTOR-GENERATOR SET

Recently an arrangement has been tried in this country which solves the problem of speed control in a most satisfactory manner. Unlike rheostatic control, it is economical and is capable of being adjusted to obtain any definite speed through a wide range, the same being kept constant irrespective of the load on the mill. This characteristic is not found in the multi-speed motor, or cascade method of control, as usually each of these methods is limited to two or three different speeds. It consists throughout of standard apparatus, with which the

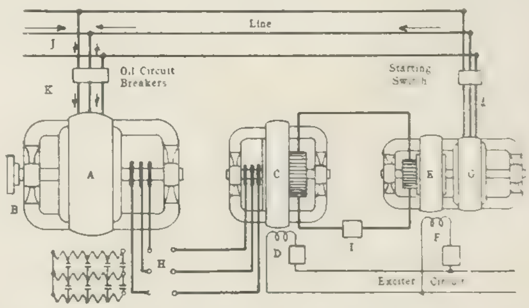


FIG. 2—DIAGRAM SHOWING COMPLETE EQUIPMENT AND LAYOUT OF ROTARY CONVERTER MOTOR-GENERATOR SYSTEM

ordinary operater is well acquainted, and when repairs are needed does not present the difficulties encountered with three-phase commutator motors with their complicated windings. The apparatus required is indicated graphically in Fig. 2.

Motor A is the main rolling mill motor, which is an ordinary rolling mill motor of the type usually installed for single speed operation, and normally operated on external grid resistance. The auxiliary apparatus described can be added to any single speed installation should new rolling conditions create a demand for a wide range of speeds.

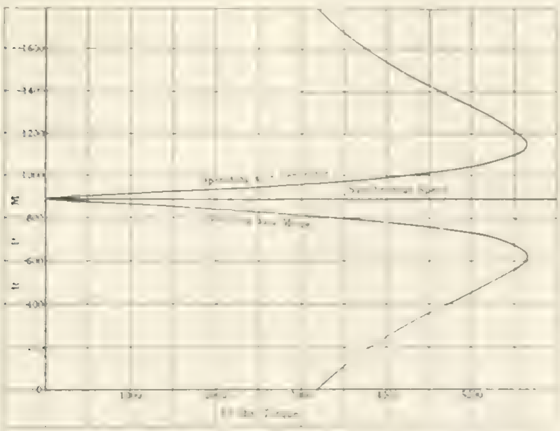


FIG. [illegible]—SLIP-TORQUE CURVES OF INDUCTION MACHINE OF MOTOR-GENERATOR SET FOR OPERATION BOTH AS A GENERATOR AND AS A MOTOR

The Rotary Converter C is a standard machine, wound with the same number of phases as the secondary of the main rolling mill motor. Its frequency and voltage rating also must be consistent with that obtained from the secondary of the large motor under operating conditions. The installation described operates at three-phase, 60 cycles, and the maximum speed reduction desired is 30 percent, which is equivalent to 18 cycles on the secondary. As the locked secondary voltage is 552 volts, the secondary voltage corresponding to 18 cycles is 166. Since the alternating voltage of a three-phase rotary converter is 61 percent of the direct voltage, 272 volts will be obtained across the direct-current terminals. A standard three-phase, 25 cycle, 275 volt rotary converter, having a capacity equivalent to 30 percent of the main rolling mill motor, meets the requirements of this particular installation.

The Motor E under normal conditions operates as an ordinary direct-current motor, separately excited, receiving electrical energy from the rotary converter and transmitting it as mechanical energy to the alternating-current generator of this set.

Generator G, in the particular installation referred to above, is a squirrel-cage induction motor, and operates as such when starting the motor-generator set, continuing to act as a motor until the auxiliary apparatus is placed in operation with the rolling mill motor. It then runs as an induction generator, returning to the main circuit electrical energy which would otherwise be lost in the external resistance.

OPERATION

It is customary to install a main rolling mill motor wound for the highest speed which will be required on the mill, the auxiliary apparatus being used to reduce the speed of this motor to the slowest speed required. In this particular instance, the auxiliary apparatus is used in conjunction with either of two motors; the schedules, so far as possible, being arranged so that the normal speed of the motor can be used on one mill while the apparatus operates with the other motor to obtain slow speeds.

Starting—When the mill is started, switch *H* is always connected to the resistance, and the motor is started up as is customary with induction motors operating on external resistance. In order to place the auxiliary apparatus in operation with this motor, the motor-generator set is started from the alternating-current end by means of an ordinary starting switch. The field on the direct-current end of this set is reduced to zero, so that the motor-generator set is simply floating on the line from the alternating-current end. Normal field should be placed on the converter and, while the main rolling mill motor is operating at light load and running with small slip, the switch *H* should be thrown from the resistance to the alternating-current side of the converter. The rotary converter rotates very slowly, since it must operate in synchronism with the slip of the main motor. The switch *I* is then closed, which completes all circuits, and places the apparatus in condition for speed adjustment by means of field control on the direct-current motor *E*.

For the Alternating-Current Generator G either a squirrel-cage induction motor or a synchronous machine will give practically the same results. The synchronous machine will keep the speed of the set at exact synchronism and, if operated at a leading power-factor, will increase the power-factor of the system. This is of no great importance, since the size of this machine is comparatively small. The induction machine is more stable, and has the advantage of greater simplicity, thus requiring less attention. It takes a wattless exciting current when operating either as a motor or generator, this wattless current being practically the same in either case.

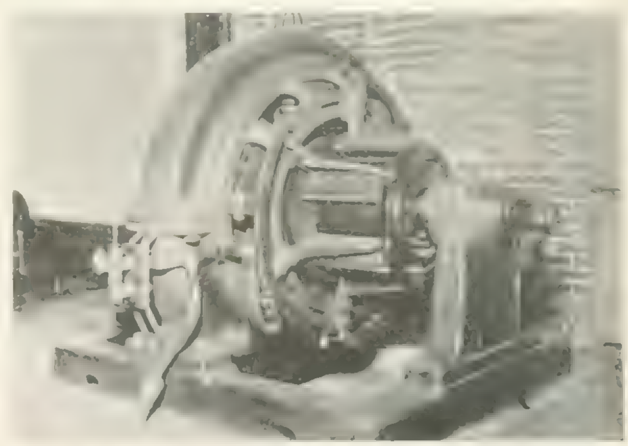


FIG. [illegible]—ROTARY [illegible] IN CONNECTION WITH THE [illegible]

In the installation shown in Fig. 1, a squirrel-cage induction machine has been used with a full-load slip of three percent. When the set is floating on the line its speed is slightly below synchronism. However, during normal operation, when acting as a generator, its speed varies from synchronism to three percent above at full load.

Direct-Current Motor (*E*)—For the present purpose, the speed of this machine can be considered as constant under all load conditions. The voltage which it generates is then dependent entirely upon its excitation. If this were a shunt machine the operation of the apparatus would be determined solely by the shunt field but, in order to obtain a slight variation in speed of the rolling mill motor between no load and full load, a small series field has been placed on the machine, so that its armature voltage will vary slightly with load. This is necessary to cause the flywheel on the mill to assume the peaks, thereby equalizing the input to the rolling mill motor.

Rotary Converter C—This machine is used to transform alternating-current to direct-current, making it impossible to obtain speed adjustment by means of the field of the direct-current motor. It is separately excited and, with its field rheostat once set for normal field current, it need never be changed. Disregarding the alternating-current end of this machine for a moment, it can be considered as a shunt-wound motor, with voltage impressed upon its brushes equivalent to the armature voltage of the motor *E*. Since its field strength is constant, its speed of rotation must be sufficient to generate the counter electromotive force to oppose the impressed voltage. Its speed or frequency at the slip rings is, therefore, in direct proportion to the impressed direct current voltage.

The excitation of the main rolling mill motor and the induction generator can come from either the main line through the primary of the motor or from the field of the converter. If the latter machine is excited to give 100 percent power-factor in its own circuit the rolling mill motor will take its excitation from the primary line and will have the same power-factor as if it were operating on resistance. However, by over-exciting the rotary converter, its excess excitation is transmitted to the secondary of the main motor and the exciting current taken from the line is reduced accordingly. By increasing the field of the rotary converter sufficiently, it may be made to excite not only the generator and main rolling mill motor, but to force exciting current into the receiving circuit, thereby giving a leading power-factor to the system.

Rolling Mill Motor A—When the large motor is operated on external resistance, its full-load slip is determined by the ohmic resistance of the secondary. For every torque value required there is a definite secondary current which must flow through the secondary windings. Since the secondary voltage is proportional to the slip, the rotor must drop sufficiently in speed to develop the required voltage at the slip rings to force this current through the external resistance. This voltage can be either entirely dissipated as IR drop in resistance, or balanced by a counter e.m.f. With the rolling mill motor running on external resistance, its speed is determined solely by the voltage required at its secondary terminals. When operating in conjunction with the apparatus outlined in this paper, its speed is fixed by the frequency of the rotary converter. Of course, the voltage is proportional to the frequency, and any departure from this relation, due to armature reaction, etc., will be compensated for by a circulating current between the converter and secondary of the large motor, as is the case with synchronous generators running in parallel. As is outlined above, it is possible to fix the frequency on the slip rings of the rotary converter, and, as the slip of the large motor is equal to the frequency of the converter, it must drop sufficiently in speed to synchronize its slip with this frequency. Since the frequency between the alternating-current terminals of the rotary converter is practically constant, irrespective of the load on the rolling mill motor, the speed of the rolling mill motor likewise is kept constant. This, as has been pointed out above, is one practical advantage of this scheme of operation over that of operating on external resistance, where the speed varies directly with the load.

SPEED ADJUSTMENT

With the field *F* reduced to zero, theoretically the armature voltage of the motor *E* is zero; and, as the direct-current end of the converter is short-circuited through this machine, its direct voltage is also zero, the converter being at standstill. Its frequency being zero, the rolling mill motor will operate as a wound-secondary induction motor with a very small external resistance. It will thus be seen that this apparatus can only be controlled from the field of the direct-current motor. With full field on this machine, full armature voltage will be obtained on motor *E*, which, in turn, fixes the same voltage on the direct-current end of the rotary converter *C*. This, in turn, determines the speed of the converter or its frequency and, as the slip of the main motor *A* must be equal to its frequency, it will drop in speed until the two are in synchronism.

EFFECT OF IMPEDANCE DROP IN CIRCUITS AND VOLTAGE REGULATION OF MACHINES

Assuming a theoretical case of no load on the large motor *A*, no current would flow in any of the circuits. Under these conditions, the direct current voltage of the circuit would be equal and opposite to that on the motor. In like manner, the alternating voltage of the converter would oppose its direct voltage, but, as soon as the load comes on, current begins to flow from the secondary of the main rolling mill motor through the auxiliary apparatus back to the line, and this exact balance is destroyed. Assuming that the motor *E* has a flat voltage regulation curve, the

voltage of the converter must increase with load to compensate for the line drop between the converter and the direct-current motor. Since the converter is operating as a shunt motor, with separate excitation, an increase in speed is required to generate this greater voltage. This, of course, means a higher frequency on

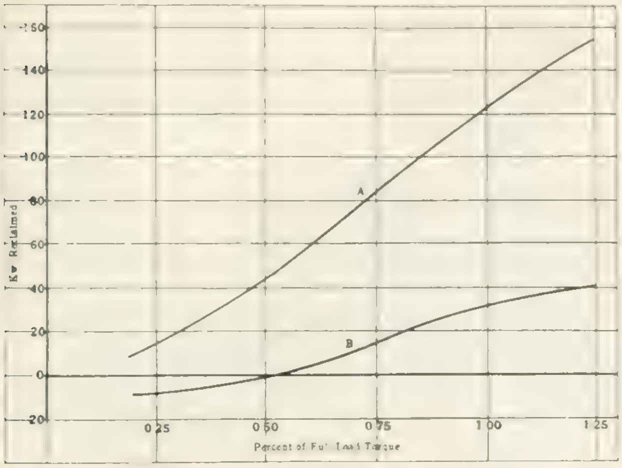


FIG. 5—CURVES OF POWER RECLAIMED
A for 30 percent speed reduction; *B* for 15 percent.

the slip rings, which causes the rolling mill motor to increase in slip. Since the large motor *A* and the converter must operate in synchronism, it is evident that the impedance of the lines between these two units has no effect on speeds of any of the machines, but the impedance between the alternating-current side of the rotary converter and the terminals of the motor *E* has the same effect on the rolling mill motor as if the motor were operated on external resistance, having an equivalent impedance.

If the motor *E* is a shunt machine, its terminal voltage will drop as the load increases. This will cause the rotary converter to decrease in speed, which reduces the frequency and, therefore, tends to raise the speed of the rolling mill motor as the load increases.

As the torque on the mill increases, the amount of power transmitted through its auxiliary apparatus also becomes greater. This causes the speed of the motor-generator set to increase in accordance with the speed-torque curve of the induction generator, Fig. 2. Such an increase in speed, of course, tends to increase the terminal voltage of the direct-current motor. This characteristic, and the impedance of the circuit between the alternating-current side of the rotary converter and the terminals of the direct-current motor, both tend to cause the rolling mill motor to drop in speed as the load increases. Opposed to these is the dropping voltage characteristic of the direct-current motor, which tends to increase the speed of this motor with increase of load.

The nature of the load on a rolling mill motor demands that flywheel effect be utilized to equalize the power input. In order to accomplish this, the motor must drop in speed with increase in load. It is, therefore, important to consider all characteristics of the various machines, and the impedance of the circuits, before designing the apparatus for the installation. If it is found that the required slip will not be obtained as the load is placed on the mill, a series field of the proper value should be placed on the motor *E*, which will cause its terminal voltage to rise as the load increases. This, of course, will tend to make the rotary converter run at a higher speed and, since this increases its frequency, the necessary speed regulation will be obtained on the main motor.

POWER RECLAIMED

Neglecting the small losses in the circuits and auxiliary apparatus, the amount of power returned to the line will be equivalent to the output at the secondary terminals of the main rolling mill motor. This energy is proportional to the product of the voltage and line amperes. The current in the various circuits is in no way influenced by any adjustment which can be made on the apparatus, but is dependent upon the load placed on the mill. In other words, for every value of torque required on the mill motor there is a definite current which must flow in its secondary circuit. The line current will then vary from that required at friction load to the peak value which will occur. It is, therefore, evident that the only manner in which it is possible to effect the power reclaimed is by voltage adjustment. With a very light field on the motor *E*, the several terminal voltages will be small. In Fig. 5 is shown the amount of power returned to the line by the generator *G*. When operating at full load and 30 percent speed reduction, 122 kilowatts are reclaimed.

LOSSES

The individual losses of each machine can be segregated, and a definite efficiency curve plotted as in Fig. 6. It should be remembered that the power input at the primary terminals of the main rolling mill motor not only includes energy transformed into mechanical power to drive the mill, but also the power returned to the line by the induction

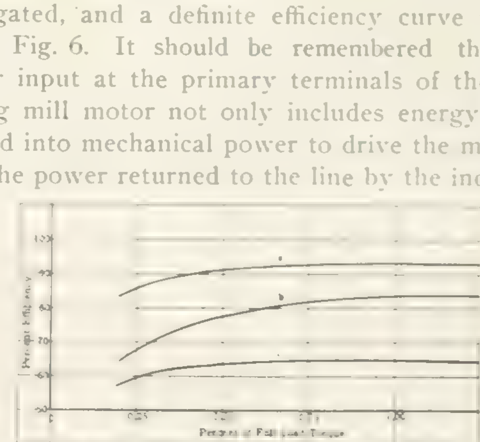


FIG. 6—COMPARATIVE CURVES OF EFFICIENCY
a—Main motor with secondary short circuited.
b—Main motor at 30 percent speed reduction by means of scheme shown in Fig. 2.
c—Main motor at 30 percent speed reduction by means of rheostatic control.

generator *G*. With the main motor operating on external resistance, the energy returned to the line would be dissipated in this resistance, and would be included in the losses. In order to give a slip of 30 percent at full load, the full-load efficiency of such an installation would be approximately 65 percent. When obtaining the efficiency of the rolling mill

motor used in conjunction with the auxiliary apparatus, we should measure the net input, which is the energy returned to the line by the induction generator *G*, subtracted from the power input to the main motor *A*. In other words, the whole outfit should be considered as a unit, and the net power

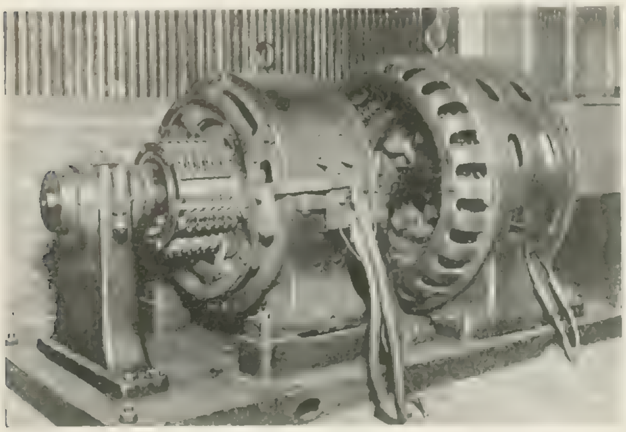


FIG. 7—MOTOR-GENERATOR SET OF TYPE USED IN THIS INSTALLATION

required is the amount taken from the incoming transmission line. The meter should be placed at *J* and not at *K*, Fig. 2.

Tests show a full load efficiency of 84 percent, with a speed reduction of 30 percent. As the speed reduction is decreased the friction and windage of the main rolling mill motor and the rotary converter change, as well as the excitation on the direct-current motor. It has been found that these several losses practically balance each other, and the efficiency is, for all practical purposes, the same throughout the speed range at which the apparatus operates.

MAIN MOTOR OPERATING ABOVE SYNCHRONISM

This scheme can also be used to increase the speed of the main motor above synchronism, as shown in Fig. 8. As the field of the motor *E* is weakened, the large motor increases in speed or

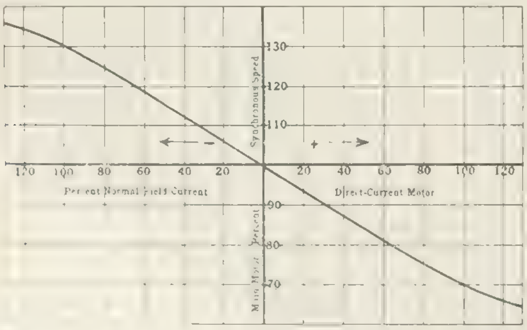


FIG. 8—[illegible] POSSIBLE SPEED RANGE OF MAIN [illegible] OF THE DIRECT-CURRENT MOTOR

approaches synchronism. The speed of this motor can be increased on through synchronism by reversing the field of *E*, and building it up in the opposite direction.

An induction motor or generator assumes a difference in load by changing its speed relative to synchronism. A synchronous machine accomplishes this by changing its phase displacement. The latter machine usually consists of a stator winding for alternating-current and a revolving direct-current field. The magnetic field of the primary and the mechanical rotor rotate at the same speed and remain in step under normal conditions.

The slip of the rolling mill motor *A* at all times is equal to the frequency of the rotary converter. When the motor is at standstill, full line frequency is developed in its secondary and the converter operates as if it were connected directly to the line. The magnetic field produced by the current in the secondary windings, therefore, rotates at the same speed as that of the primary, and is in step with it. Under these circumstances, the operation is similar to that of a synchronous machine. Now, if the induction motor is rotating slowly the rotary converter will run at a slower speed, its speed being equivalent to the slip of the induction motor. Assume that the mechanical speed of rotation is equivalent to five cycles; then the frequency of the rotary converter is $(60-5)=55$ cycles, and the magnetic field of the secondary is rotating at the

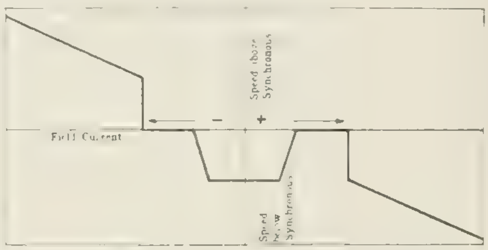


FIG. 9—DIAGRAM SHOWING SPEED VARIATION OF THE MAIN MOTOR IN PASSING THROUGH SYNCHRONISM

This is an enlarged portion of the curve shown in Fig. 8.

rate of 55 cycles per second or five cycles slower than that of the primary. But the rotor of the induction machine mechanically advances the secondary field five cycles per second, so that the two fields are in synchronism and we again have the operating characteristics of a synchronous machine. This condition holds until the induction motor nearly reaches synchronous speed. At this time the rotary converter is turning over very slowly. If the latter had no losses, it would rotate until the continuous voltage impressed on it was reduced to zero; but, due to friction, it will stop some time before arriving at this point, as shown in Fig. 9. With the rotary converter at standstill, direct-current flows in the secondary of the induction machine, which causes it to rise to synchronism, giving an exact duplicate of the ordinary synchronous motor operation. This continues until the field of *E* is weakened to such an extent that the direct-current is not sufficient to excite the secondary of the mill motor, which then takes on the characteristics of a wound rotor induction motor, with its slip rings short-circuited through the rotary converter. This causes it to drop slightly below synchronism, as is shown in Fig. 9. The field on the direct-current machine is now reversed and when the field current is in-

creased sufficiently to excite the induction motor, it again acts as a synchronous machine, coming up to synchronous speed. Reversing the field of the direct-current machine, of course, is equivalent to reversing the polarity of the field of a synchronous machine. This results in the machine slipping a

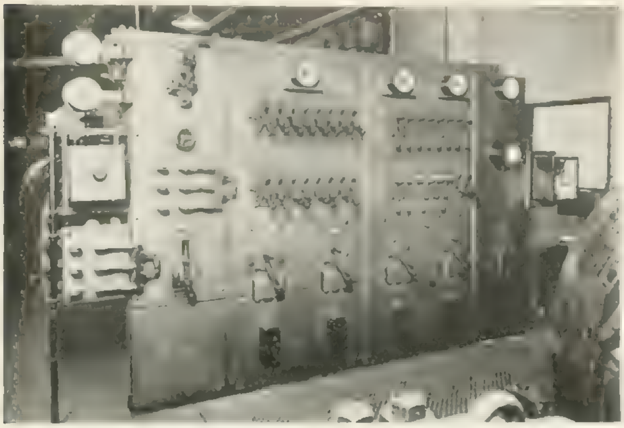


FIG. 10—SWITCHBOARD USED IN THE CONTROL OF THE COMPLETE INSTALLATION

pole; that is, the polarity of the secondary has been shifted 180 degrees. If the field current is increased until sufficient energy is supplied to start the rotary converter, the slip of the induction motor again synchronizes with the frequency of the converter. The field of the latter has not been changed, so that its rotation will be reversed by the opposite transmission of power. Heretofore, it has rotated in such a direction as to subtract its frequency from synchronism. When its rotation is reversed, this frequency is added to that of synchronism, and the main motor runs at a speed equivalent to the line frequency, (60 cycles, in this case) plus the frequency of the rotary converter.

The direct-current machine continues to rotate in the same direction, on account of its being tied in with the alternating-current line by means of an induction machine. Since this field has been reversed, we have reversed the direction of energy. In other words, it is acting as a generator, taking power from the three-phase line through the alternating-current end of the set. The induction machine is now operating as a motor, driving the direct-current machine as a generator, which in turn supplies power to the rotary converter.

This increase in speed can be continued until the auxiliary apparatus has reached its rated capacity which, with this installation, is 30 percent of the main rolling mill motor. It is, therefore, evident that the usefulness of this apparatus is doubled in obtaining a wide range of speed. In laying out such a scheme, it is necessary to install flywheels which will run at the higher speed. In addition to this, attention must be given to the characteristics of the machine and circuits, so that adequate flywheel effect will be obtained at speeds above synchronism. A smaller percent regulation at speeds above synchronism is sufficient to give the same effect that is obtained below synchronism. This, of course, is due to the fact that the amount of energy stored in a moving mass increases as the square of its speed.

Since the value of energy transmitted from the rotary converter to the motor-generator set, or vice versa, is equivalent to the product of the current and voltage, a counter transmission can only take place when either one of these components is reversed. Changing both would in no way effect the product. The voltage on the direct-current machine *E* is reversed by the field, its direction of rotation remaining the same. The voltage of the rotary converter is reversed by the opposite rotation of its armature, while its field current continues in the same direction. The armature current between these two machines, therefore, always flows in the same direction, irrespective of the function the auxiliary apparatus may be performing. A single reading ammeter can be used in this circuit but the voltmeter should be double reading.

ROTARY CONVERTER DIRECT CURRENT MOTOR SET

The apparatus which is described above is suitable for application where the torque remains constant, irrespective of the speed, but when the torque increases with the speed a modified arrangement of the apparatus can be made to give constant horse-power output. To accomplish this the direct-current motor *E* is coupled to the main motor *A*, as in Fig. 11, and the surplus power is reclaimed as mechanical energy.

On many mills the cross section of the billet or bloom rolled remains practically constant, irrespective of the size to which it is finished. The larger product is obtained by reducing the total number of passes in the mill. This may result in a schedule having fewer pieces of metal in the rolls at any one time so that the torque required by the motor is often less than when rolling a smaller product, and the motor-generator scheme is best adapted to a mill having this type of schedules. However, on some mills when a

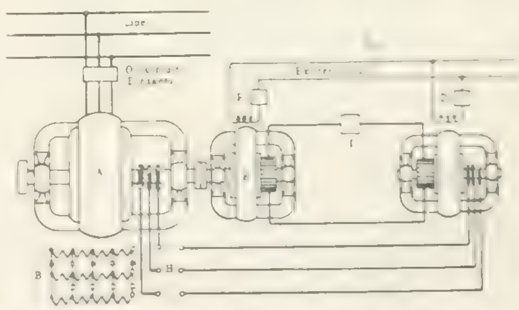


FIG. 11—DIAGRAM SHOWING ARRANGEMENT AND CONNECTIONS OF APPARATUS IN THE CONSTANT HORSE-POWER ROTARY CONVERTER-DIRECT-CURRENT GENERATOR SYSTEM

larger finished product is rolled the size of the billets is increased to such an extent that the torque actually is greater than is required when rolling the smaller product. The large billets also may be of a higher carbon or an alloy, which would naturally increase the driving torque required so that the constant horse-

power proposition, as shown in Fig. 11, would be the logical installation to make.

The performance of the main motor from the electrical point of view is identical in either of the two schemes. The final result depends entirely upon the disposition of the power given up by its secondary winding. Neglecting the small losses in the auxiliary apparatus, power in the latter scheme is utilized in mechanically aiding the prime mover. The operation of the whole outfit is similar to that of an adjustable speed machine tool motor, in which the torque varies inversely as the speed.

APPARATUS

On many applications the speed of the main motor is comparatively slow, depending on the operating speed required by the apparatus which it drives. Since, with the constant horse-power scheme, it is preferable to couple the motor *E* to the main drive, it operates at a comparatively slow speed, and may, therefore, be unusually large for its rated output. Its cost may offset that of the motor-generator set in the first scheme, since the speed of the latter is not influenced by other apparatus and can be designed to operate at the most economical speed.

The motor *E* is designed to give full output at the slow speed, but must be mechanically constructed to withstand a no-load over speed equivalent to that obtained when the main motor operates at approximately synchronism. If the outfit is used above synchronous speed, the motor *E* must carry full load at the maximum speed obtainable.

OPERATION

The operation and speed adjustment is similar to that of the rotary-converter motor-generator scheme, but the function of the series field of the direct-current motor is modified somewhat, due to the fact that its speed varies with that of the mill motor. With the former scheme the speed of the direct-current motor remains practically constant, irrespective of the load on the main motor, as the slip of the induction generator is very small. Since the speed of the direct-current motor must be the same as that of the main motor, the series field must be increased to compensate for the drop in armature voltage, due to the decrease in speed as the load on the prime mover becomes greater. Since the ordinary mill drive requires from 10 to 15 percent speed regulation, this amount of compounding must be added to that which would otherwise be needed with the constant torque proportion.

APPLICATION TO FANS

This apparatus can be very well adapted to mine fans where a slow speed is wanted at first, but, as the mine is enlarged, the amount of air required increases, and the speed of the fan must be raised to meet the greater demand. On rolling mill applications, after the main motor is started the transfer switch *H*, Fig. 2, is thrown, when the mill is operating under light load, but this cannot be done on some fans, and it, therefore, becomes necessary to supply a modified form of transfer switch. Under these conditions it is preferable to supply a rocker type of switch, with a double row of contacts on the side connecting the rotary converter. Each of these additional contacts is connected to its mate by means of a preventive resistance. Before the transfer switch leaves the contacts on the left side, the blades on the right engage the dummy contacts, and the secondary of the main drive is connected to the rotary converter through the preventive resistance. The same principle is commonly used in connection with storage batteries, where it is necessary to place in circuit additional cells without disconnecting the circuit. The switch can be thrown very quickly, so that the current flows through the preventive resistance only for an instant, but, in this manner, breaking the circuit under full-load conditions is avoided.

When the mine becomes sufficiently developed to demand the full speed of the fan, the auxiliary apparatus need no longer be used for this purpose. Since the direct-current motor or motor generator set and rotary converter are standard apparatus, they can be placed in some other service for which they are more commonly used.

The torque of the fan varies as the square of the speed. Of the two schemes the motor-generator method, giving constant torque, is inherently better adapted for this application. If the speed of the fan is comparatively high it may be more economical to couple a direct-current motor to the prime mover instead of using the motor-generator scheme. The particular proposition in question must be decided upon its own merits, as successful operation can be obtained with either method.

CONCLUSION

This principle is analogous to that of placing a low pressure steam turbine in a plant to utilize the exhaust steam from a reciprocating engine. With the engine operating alone, the energy which still remains in the exhaust steam is lost. In like manner, the power which passes from the secondary terminals of the induction motor to the external resistance is dissipated as heat. By passing it through this auxiliary apparatus, certain losses take place, similar to that in the low pressure steam turbine, but a large percentage is returned to the line.

If only one speed is required on the mill, a single speed motor should be used by all means, as this requires only the simplest type of apparatus and therefore insures great continuity of service, which is very important in steel mill work. In most cases, where a single speed is not sufficient, it is generally found that a two speed motor fulfills all the requirements actually needed. In many cases operators find that they can confine themselves to one of these two types of motors, but where it is necessary to install apparatus for more than two speeds the scheme described herein is a simple solution, consisting of standard apparatus which has demonstrated its success in actual operation.

A Load-Proportioning Arrangement

B. H. SMITH

A FEW YEARS AGO, direct-current systems were quite generally used in such applications as steel mills, but the advantages of alternating current have been so numerous as to cause it to supplant the direct-current systems to a very large extent. In this transition it has sometimes occurred that the direct-current plant has not been replaced outright, but alternating-current apparatus has been installed, in addition, to take care of growing power requirements.

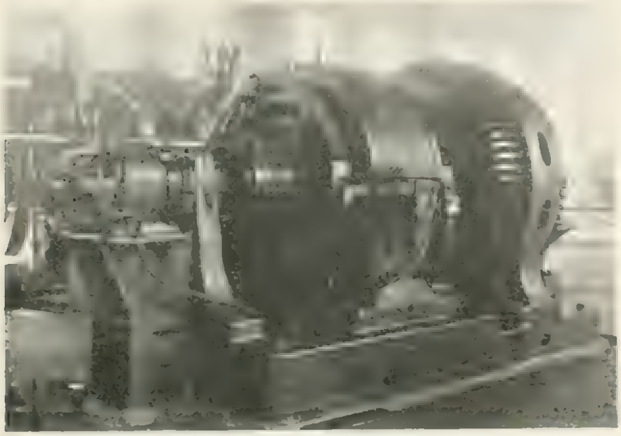


FIG. 1—MOTOR-GENERATOR SET CONNECTING ALTERNATING AND DIRECT-CURRENT SYSTEMS

This set consists of a 300 kilowatt, 250 volt, direct-current generator and a 250 horse-power, 440 volt synchronous motor.

The load in a steel mill is extremely variable, and much could be saved in the cost of the generating installation if it were not necessary to make provision for excessive peaks. In many cases it has been found profitable on direct-current systems to install a storage battery of large capacity, arranged to "float" on the line in such a way that the load on the generating apparatus is practically constant. Such an arrangement is impossible in an alternating-current system, and in many direct-curent systems the cost is prohibitive. However, in cases where the original direct-current installation is increased by an alternating-current outfit, it is quite possible to arrange the apparatus in such a manner that the total load on the generating system is practically uniform, although at times the load on either the direct-current or the alternating-current line may be heavy. This result is brought about by a motor-generator set, such as shown in Fig. 1, so connecting the two systems that, in case either is excessively loaded, power is furnished one system from the other. In other words, the function of the motor-generator set is to balance the load. This method is used in the plant of the Riter-Conley Co., Pittsburgh, Pa., and the connections for the outfit are indicated in Fig. 2. It will be observed that the direct-current end of the motor-generator set has only a shunt field winding, since a series field would buck the shunt field when the machine is operating as a motor. When generating, the machine must parallel properly with the direct-current source, so that there is, especially at light loads, an extremely unstable condition; for, if the generator of the motor-generator set, shown at *A* in Fig. 1, should start to feed into the other direct-current generators, the series windings on the latter would immediately decrease their field strengths, thus lowering the counter e.m.f. and in a very short time the rush of current resulting would trip the circuit breaker. Hence, it becomes necessary to arrange whatever control apparatus is used on the field of the generator in such a manner that under no circumstances will its generated voltage be great enough to feed power into the other direct-current generators.

As may be seen from Fig. 2 the field of the generator is controlled by a balancing relay. A connection and winding diagram of this relay is shown in Fig. 3 and its appearance when installed is shown in Figs. 4 and 5. The total load on the direct-current generators is measured by the upper element of the relay and the total load on the alternating-current generators is measured by the lower element. The two

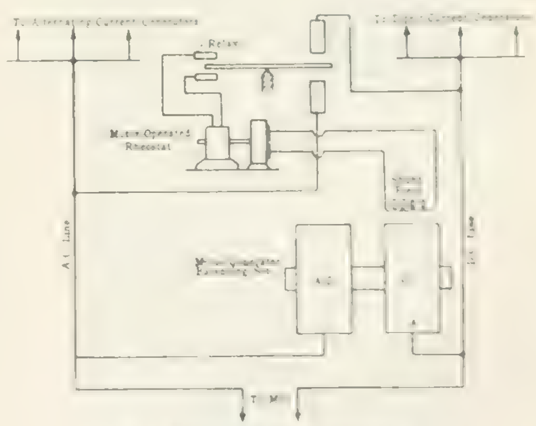


FIG. 2—CONNECTION DIAGRAM

[illegible] tioning the load between the direct and the alternating-current lines.

elements are connected mechanically by a thin metal strip, so that, if the alternating-current load is greater, the upper contact will close, opening the lower contact, and vice versa. The control circuit through these contacts operates the automatic field rheostat Fig. 2, thus weakening the field when the upper contact is closed and strengthening it when the lower contact is closed.

The alternating-current machine of the motor-generator set is connected to run in synchronism with the alternating-current system. Hence, if power is applied to it, tending to drive it faster than the frequency of the system will permit, it acts as a generator feeding

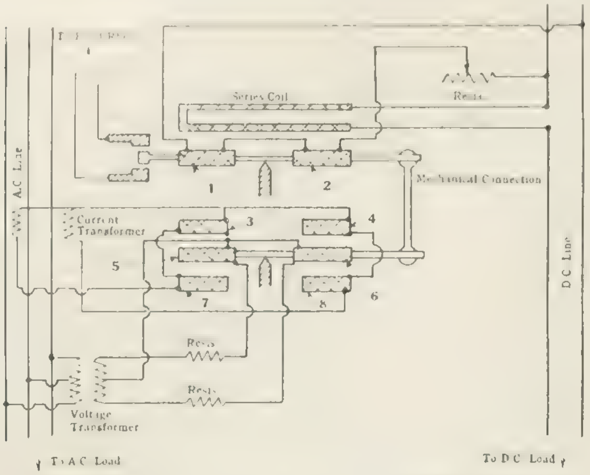


FIG. 3—DETAIL CONNECTION DIAGRAM OF GOVERNING RELAY SHOWN IN FIG. 2

1 and *2*—D. C. shunt coils. *3*, *4*, *7* and *8*—A. C. series coils. *5* and *6*—A. C. shunt coils.

energy into that system. If a mechanical load is connected to it in any way it takes energy from the system as a synchronous motor.

When the balancing set is simply "floating" on the line and taking just enough energy to overcome its friction and other losses with normal ratio of alternating-current and direct-current, the first effect of a sudden large increase of direct-current load, is to unbalance the relay and thus close the lower contact.

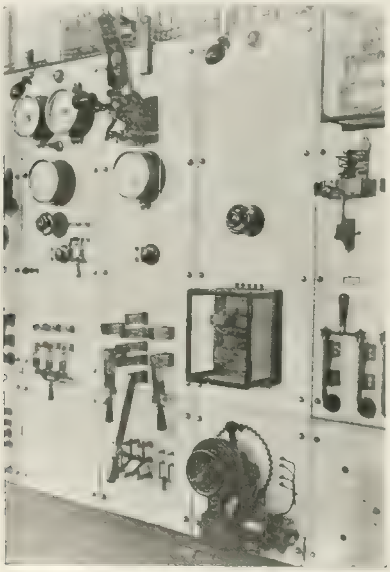


FIG. 4—VIEW SHOWING THE APPEARANCE AND LOCATION OF THE RELAY ON THE STATION SWITCHBOARD

The automatic rheostat responds and increases the field current of the direct-current machine *A* raising its voltage. As a result power is delivered to the direct-current system and taken from the alternating-current system in increasing amounts until the relay becomes balanced and the rheostat stops. Again, if the alternating-current load in the mill is greatly increased, the relay again becomes unbalanced, but this time the alternating-current element has the greater torque and, therefore, the upper contact closes. The rheostat now turns in the opposite direction, the field current decreases and the machine *A* acts as a motor, transferring power from the direct to the alternating-current side until the relay again becomes balanced with both of its contacts open.

The relay may be adjusted for various ratios of alternating to direct-current power, such as 1 to 1, 2 to 1, etc., according to the desire of the operator. Thus, if only one direct-current generating unit is running and several alternating-current units are in operation, the ratio might be as great as 6 to 1.

In some of the earlier installations, an interesting point was brought out in connection with the demand for the above mentioned ratios of power. It was proposed to add a weight to one side of the relay balance

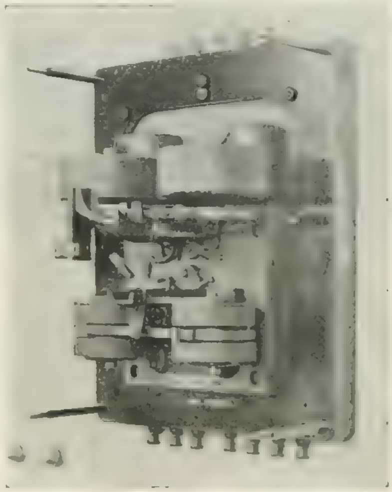


FIG. 5—DETAIL VIEW OF RELAY WITH GLASS COVER REMOVED

arm to allow for a given excess of alternating-current power. This arrangement worked very well as long as there was some load in the mill, but if by any chance the total load became small, the weight on the relay arm would close the lower contact and raise the voltage of machine *A* to an excessive value. The final arrangement, however, consisted in placing a variable resistance in the voltage winding of the direct-current element of the relay by means of which its calibration might be varied at will, thus giving the various ratios required. By this scheme the mechanical balance of the instrument remains undisturbed and, when the total load becomes light, the contacts remain open and the voltage of machine *A* remains normal. In fact, it is found that the mechanical balance of the relay should just barely close the upper contact and then at zero load in the mill the result would be to give the direct-current end of the motor-generator set a voltage just low enough so that its frictional load, etc., is carried by power from the direct-current system.

Shop Testing of Electrical Apparatus—XVII

SINGLE-PHASE TRANSFORMERS (Cont.)

CORE LOSS

THE CORE LOSS is made up of two parts, the hysteresis loss, due to the cyclic reversals of magnetism in the core, and the eddy current loss, due to current set up in the iron by the varying magnetic flux. The core loss is a function of the voltage, wave-shape and frequency. Guarantees are based, therefore, on normal rated voltage of sine wave shape at normal frequency, but the standard conditions as to wave shape are difficult to obtain in practice. However, for any wave shape there is some equivalent voltage that will produce the same core loss as would the sine wave of normal rated voltage at normal frequency. This voltage is determined by an instrument called the core loss voltmeter, which indicates normal voltage when the actual root mean square voltage impressed on the transformer is such that the core loss is the same as would be produced by a sine wave of the same frequency at normal voltage.* The instrument is provided with two scales, one calibrated in volts to agree with the root mean square voltmeter on a pure sine wave, the other calibrated to indicate the watts loss in the instrument.

In practice, the core loss voltmeter is connected across the terminals of the transformer under test in the same manner as an ordinary voltmeter. A wattmeter is connected in the circuit in such a manner as to measure the total input of both the transformer and the core loss voltmeter. The voltage of the circuit is then adjusted until the core loss voltmeter indicates the normal voltage of the transformer. The total power input is then read on the wattmeter and the watts input of the instrument is read on the watt scale of the core loss voltmeter, the difference being the normal core loss of the transformer. When used on a peaked voltage wave, the core loss voltmeter will indicate a lower value than the root mean square voltmeter, and vice versa.

The voltage employed to measure the core loss of a transformer may be impressed upon either the low tension or high tension winding, or a portion of the winding, care of course being taken that the voltage used is normal voltage for the winding or portion of the winding used. As a rule, the voltage should be impressed on the total low tension winding. In case, however, of a transformer having a number of coils in the low tension winding for parallel or series connection, and should the series connection require a low tension voltage which is too high to be conveniently obtained or accurately measured, then the core loss should be measured with all the coils in parallel rather than upon one coil of the series. Should it become necessary in extreme cases to measure the core loss on a portion of the winding, either in series or parallel, less than 25 percent of the winding should never be used. Core loss should be measured with the transformer at as near 25 degrees C as possible.

The exciting current of a transformer is that current which flows in the winding to supply the magnetization and the core losses and is measured as the current flowing to the primary with the secondary circuit open. The volt-amperes excitation (apparent watts) is the product of the exciting current and the voltage used in making the test. The exciting current is made up of two components, the iron loss and the magnetizing components, at right angles to each other. The iron loss component equals the watts core loss divided by the rated voltage. The magnetizing current =

[illegible]

If the voltage employed in making the test is higher than can be measured directly with a voltmeter, then the voltage transformer used in connection with the same should have a primary voltage rating corresponding approximately to the test voltage, and should have such a ratio as to give a reading on the most accurate part of the voltmeter scale. If a current transformer is necessary in connection with an ammeter or wattmeter, it should have a maximum line voltage rating equal to or greater than the test voltage, to ensure against breakdown.

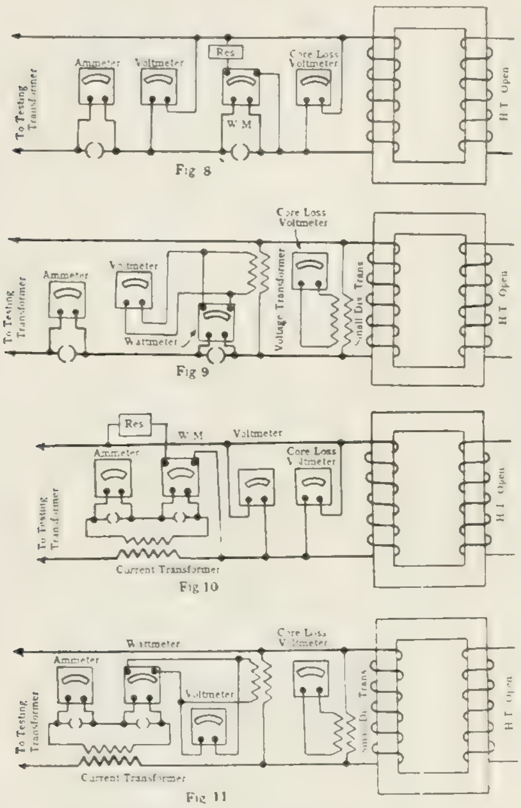
Four diagrams of connections for testing for core-loss are shown in Figs. 8, 9, 10 and 11, all meters and instrument transformers being shown connected correctly in the circuit. That scheme of connection should be used which is most suitable to the current capacity and voltage of the transformer to be tested and the instruments available. When using an external resistance in the potential circuit of the wattmeter, it should always be connected as shown in Fig. 8 and Fig. 10, as this method of connection gives the minimum voltage strain between the potential and current coils.

With the connections shown in Figs. 8 to 11, the ammeter and wattmeter register the losses in the two voltmeters. If the source of potential is constant, the voltmeters may be disconnected while taking the wattmeter and ammeter readings. If, however, the voltage is fluctuating, the voltmeter and wattmeter must be read simultaneously, and the losses corrected for.

*For a more detailed description of this meter, see the JOURNAL for April, 1911, p. 383. The current taken by this type of instrument is so great that it should not be used with an ordinary potential transformer, but a small distributing or power transformer should be used.

The ammeter and wattmeter current coils should always be short-circuited, except when readings are being taken.

In starting the test, a low voltage should first be applied and the value of the current noted. If the ammeter indicates an excessive value, the oil-switch should be opened and the transformer examined for improper connections on the terminal boards and for possible short circuits on other parts of the winding. If, however, the ammeter indicates a value of current commensurate with the voltage applied and the size of the transformer being measured, the ammeter should be short-circuited and the voltage on the transformer increased until the core loss voltmeter indicates the normal rated voltage of the transformer.



FIGS. 8, 9, 10 AND 11—FOUR METHODS OF CONNECTION FOR THE MEASUREMENT OF CORE-LOSS

The voltage of the testing circuit as indicated by the r.m.s. voltmeter should be noted when the core loss voltmeter indicates the normal rated voltage of the transformer. The ammeter and wattmeter readings are then taken, and the connections noted, so that corrections may be made if necessary. The volt-amperes (apparent watts) are computed from the observed value of exciting current, and the normal voltage of the winding as indicated by the core-loss voltmeter.

When the transformer is connected as shown in Figs. 8 to 11, the wattmeter indicates in addition to the core loss of the transformer, a small copper loss due to the exciting current of the transformer, which is so small that it can be neglected. The copper loss in the potential circuit of the wattmeter and the core loss of the voltage transformer when one is used are, however, also measured. These losses must be subtracted from the total reading of the wattmeter in order to get the true value of the core loss. When the schemes of connections indicated in Figs. 8 and 10 are used, the correction may be easily calculated since the resistance of the potential circuit of the wattmeter and the r.m.s. voltage are known. The correction in these two cases equals $\frac{E^2}{R}$, in which E is the r.m.s. voltage applied to the wattmeter. The correction to be applied with the connections indicated in Fig. 9 or 11 may be most easily found by observing the wattmeter when the instruments are connected as in the test, but with the transformer disconnected, or the correction may be found by computing the copper loss in the potential circuit of the wattmeter as directed above, and adding to this the core loss of the potential transformer. When large transformers are being tested, the percentage losses in the meters are usually so small they may be neglected.

COPPER LOSS AND IMPEDANCE

The copper loss of a transformer, expressed in watts, is the power consumed in circulating the current through the high tension and low tension windings. This loss, usually expressed as the I^2R loss of the transformer, may be determined by calculation from the resistance and normal currents of the respective windings, or may be measured directly by means of a wattmeter.

Copper Loss by Calculation—The resistance of the high tension and low tension windings having been previously measured, and the normal current ratings of the windings being known from the k.v.a. and voltage ratings, the total I^2R loss may be calculated as follows: (H. T. current)^2 $\times$ (H. T. resistance) $+$ (L. T. current)^2 $\times$ (L. T. resistance) $=$ total I^2R loss.

Copper Loss by Direct Measurement—The most convenient method for determining the total copper loss and the true effective resistance of the transformer is by the wattmeter-impedance method. To measure this total loss, one winding is short-circuited and sufficient voltage is impressed on the other winding to cause full-load current to flow. A wattmeter in the circuit will then indicate the total copper loss plus a negligible iron loss due to the small amount of flux necessary to cause the full-load current to flow in the short-circuited winding. This total loss, as indicated by a wattmeter, will usually be larger than the calculated I^2R value on account of eddy currents or unequal distribution of current in the conductors, and the small core loss previously mentioned. In case a large discrepancy is noted between the copper loss values as obtained by the two methods, the copper loss should be measured at reduced frequency as a check on the previously measured value. If the discrepancy is due to eddy currents or to unequal current distribu-

tion, the copper loss as measured at reduced frequency will be smaller than at normal frequency.

Impedance—When an alternating current flows in a circuit there is not only the voltage drop due to the ohmic resistance, but also an additional drop at right angles to the ohmic drop due to the reactance of the circuit. The vector sum of the reactance and the ohmic resistance gives the impedance of the circuit, usually expressed in equivalent ohms. Since the reactive component of the impedance varies directly with the frequency, it is imperative that the frequency used in measuring the impedance be accurately known.

The impedance drop of a transformer is the number of volts which must be impressed on one winding

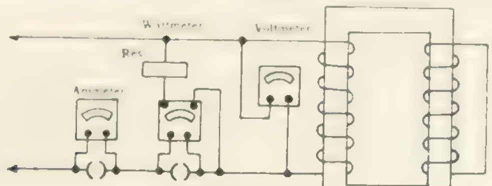


Fig 12

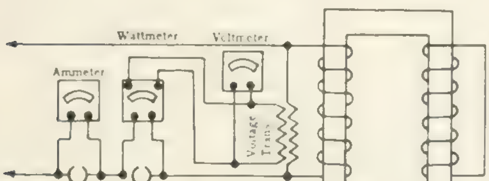


Fig 13

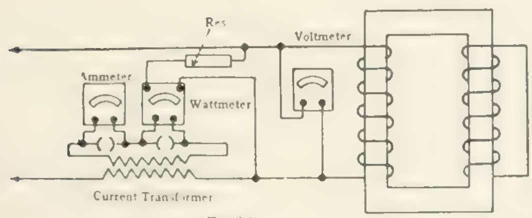


Fig 14

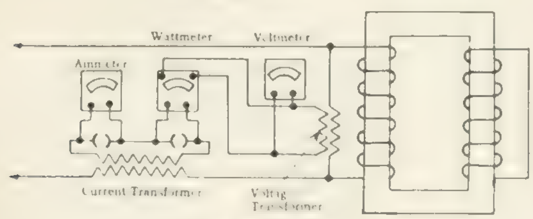


Fig 15

FIGS. 12, 13, 14 AND 15—CONNECTION DIAGRAMS FOR THE MEASUREMENT OF IMPEDANCE

Fig. 12—For low voltage, small capacity.
Fig. 13—For high voltage, small capacity.
Fig. 14—For low voltage, large capacity.
Fig. 15—For high voltage, large capacity.

of a transformer to cause full-load current to flow when the other winding is short-circuited. This impedance drop is usually expressed as a percentage of the normal rated voltage of the winding and varies between three and nine percent of the normal rated voltage, depending upon the design of the transformer. The current capacity of the ammeter, wattmeter and current transformer can be determined from the kilovolt-ampere rating and the voltage rating of the transformer.

To measure copper loss and impedance, the transformer and instruments should be connected according to whichever of the diagrams shown in Figs. 12 to 15 is the most suitable to the impedance voltage and full-load current of the winding on which the test is to be made. This test is usually made on the high tension windings, because the current and voltage to be measured come more nearly within range of the meters. The transformer winding should be connected for normal operation and the low tension short-circuited. When transformers are designed for series-parallel connection the measured copper loss with the coils connected in parallel will usually be a little larger than with the coils connected in series, due to a slightly unequal distribution of current in the various coils. Special care should be taken when short-circuiting the low tension to be sure that all connections are tight, and that the wire or cable used is of sufficient size to carry the low tension current with a negligible loss.

After the transformer has been properly connected the oil-switch connecting it to the power-circuit should be closed and a low voltage applied. The voltage should be varied by a variable ratio transformer, or by excitation of the generator, as cutting down the voltage with a series resistance is liable to give erroneous results. The switch short-circuiting the ammeter should then be opened and the current noted. If the current noted is commensurate with the voltage applied and the size of the transformer, the voltage should then be increased until the ammeter indicates the normal rated current of the winding. The voltage across the terminals of the transformer should then be observed and recorded. This voltage should always be read on the terminal board of the transformer, since there may be an appreciable drop in the leads connecting the transformer to the testing table. After the impedance voltage has been observed and recorded the voltmeter should be disconnected, if the source of the potential is constant, and the wattmeter reading observed and recorded. If the voltage is fluctuating, simultaneous readings must be taken, and the loss in the voltmeter, which is included in the wattmeter reading, must be corrected for.

The temperature of the transformer at the time this test is made should be carefully noted, so that the copper loss may be corrected to 25 degrees C. For this purpose thermometers should be inserted between the coils in such a manner as to be as nearly as possible in contact with the copper in the transformer. Usually thermometers placed against the low-tension coils will indicate very nearly the actual temperature of the copper on account of the relatively small amount of insulation between the thermometer and the copper. The effect of temperature on the impedance drop can usually be neglected. When the scheme of connections shown in Fig. 12 is used and the readings taken as directed, the wattmeter will indicate the total copper loss in both the high tension and low tension sides of the transformer, plus a negligible iron loss as previ-

ously mentioned, and the loss in the potential circuit of the wattmeter. The correction for the I^2R loss in the potential circuit of the wattmeter may be easily calculated since the resistance of the circuit and the applied voltage are shown. The correction equals $\frac{E^2}{R}$, in which E is the impedance voltage and R the resistance of the potential circuit of the wattmeter. When the instruments are connected, as shown in Fig. 13, the correction may be obtained by observing the wattmeter reading when the instruments are connected, but the transformer disconnected or the correction may be found by computing the copper loss in the potential circuit of the wattmeter as directed above, and adding to this the core loss of the potential transformer, the applied voltage being the same as the impedance voltage of the transformer.

On low voltage transformers of high current output, such as are used for electric welding purposes, it is sometimes difficult to secure instruments or current transformers capable of measuring the current. In this case it is possible to obtain quite accurate readings from the transformer ratio by separating the primary current into its components of load and magnetizing

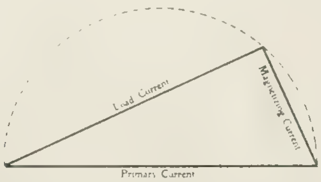


FIG. 16—METHOD OF SEPARATING PRIMARY CURRENT INTO ITS LOAD AND MAGNETIZING COMPONENTS TO DETERMINE SECONDARY CURRENT BY RATIO WITHOUT THE USE OF INSTRUMENTS

current, as shown in Fig. 16. The secondary current will then be equal to the load current in the primary, multiplied by the ratio of the primary and secondary turns.

Reactance—The percent reactance drop, which is in quadrature with the resistance drop, =

$\sqrt{(\text{percent impedance drop})^2 - (\text{percent resistance drop})^2}$.

REGULATION.

Regulation is defined in the standardization rules of the American Institute of Electrical Engineers as "the ratio of the rise of secondary terminal voltage from rated non-inductive load to no load (at constant primary impressed terminal voltage) to the secondary terminal voltage at rated load." The regulation of a transformer can be measured by applying the rated load and noting the rise of the voltage in the secondary circuit when the load is thrown off, the primary voltage being maintained constant. In practice it is difficult to obtain reliable results in this way, owing to the variations in the primary voltages which are difficult to guard against and the very small difference in voltage which is to be measured; a very slight error in reading a meter will furnish a large percent error. Hence, it is customary to calculate the regulation from the results of the tests previously outlined.*

Short-cut formulae sufficiently accurate for commercial testing are:—

For non-inductive load.

Percent regulation = (percent copper drop) + [(percent reactance drop)^2÷200)].

The percent copper drop = I^2R loss (either measured or calculated from the resistances) ÷ by the rated output, multiplied by 100.

The percent reactance drop =

$\sqrt{(\text{percent impedance drop})^2 - (\text{percent copper loss})^2}$.

For an inductive load, the following formula is more accurate:

Percent regulation =

$$I^2R \cos\theta + IX \sin\theta + \frac{(IX \cos\theta - I^2R \sin\theta)^2}{200}$$

Where I^2R equals the percent copper loss, which is equal to the copper drop expressed in percent of rated voltage.

IX equals the total reactance drop expressed in percent of rated voltage =

$\sqrt{(\text{percent impedance drop})^2 - (\text{percent copper loss})^2}$

Cos θ = power-factor and sin $\theta = \sqrt{1 - (\text{power-factor})^2}$.

EFFICIENCY.

The efficiency of a transformer is the ratio of its net power output to its gross power input. These items can be measured directly by the use of wattmeters in both primary and secondary circuits, but can usually be calculated from the tests made, as described above, with a much greater degree of accuracy. The losses in the transformer consist of two components; one a constant loss, known as the core loss, and the other a loss which varies as the square of the load, known as the copper or I^2R loss. The copper loss is usually calculated from the resistance measurements corrected to 25 degrees C. The percent efficiency then equals the output divided by (output + core loss + copper loss) × 100. From this formula the efficiency can be readily calculated for any load.*

For distributing transformers or for any transformer which is constantly excited or which carries a load for only a portion of a day, the all day efficiency becomes of importance. In this case the total losses in the transformer during the twenty-four hours should be calculated, being equal to the core loss in watts times 24, plus the copper loss for a given load multiplied by the number of hours the load is on. The twenty-four hours efficiency then equals the total output during twenty-four hours divided by the output plus the twenty-four hour loss. Ordinarily, distributing or lighting transformers are considered as carrying full-load continuously for four hours a day and no load for twenty hours, as a basis for determining the all-day efficiency.

*See article by J. F. Peters in the JOURNAL for Dec., 1911, p. 1115.

(To be continued)

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest, information involving the specific design of individual pieces of apparatus cannot be supplied. **Care should be used to include all data necessary for an intelligent answer.**

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self addressed stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time **should be allowed before expecting an answer.**

1054—Determining of Amount of Unbalancing—Given an unbalanced three-phase load fed from two transformers connected in open delta, how can the method outlined by Mr. C. H. Porter in an article, entitled, "Notation for Polyphase Circuits," in the [illegible] September '07 [illegible] applied to show currents and their phase relations in these transformers? What is the best way of predicting the amount of unbalance of secondary voltages and primary currents in a case of this kind? E. C. E. (Oregon)

This can best be explained by assuming an unbalanced load, such as is given in Fig. 1054 (a) and constructing a radial vector diagram, Fig. 1054 (c). The same notations and direction in which positive and negative angles are measured will be used as was used in the article by Mr. C. H. Porter, re-

FIG. 1054 (a), (b) AND (c)

ferred to in above question. Referring to Fig. 1054 (a), the load taken from the open phase of the delta is 250 amperes at 80 percent power-factor; from phase *A-B*, 150 amperes at 100 percent power-factor; and from phase *B-C*, 200 amperes at 90 percent power-factor. Assume the no load voltages to be 120 degrees apart and of equal magnitude. Fig. 1054 (a) gives the phase relation of the no-load voltages between lines. To construct the vector diagram, Fig. 1069 (c), lay off the no-load voltages E'_{BC}, E'_{AB} and E'_{CA} parallel to the same values in Fig. 1054 (b) and to some convenient scale to represent their magnitude. Then draw in the load currents $I_{AB} = 150$ amperes in phase with E'_{AB}, $I_{BC} = 200$ amperes lagging 26 degrees (corresponding to 90 percent power-factor) behind E'_{BC} and $I_{CA} = 250$ amperes lagging 37 degrees (corresponding to 80 percent power-factor) behind E'_{CA}. The currents in line *AA*. and transformer *1* are equal and are the resultant [illegible] as shown in (c) ($I_{AC} = I_{CA}$). This current lags θ_1 degrees behind voltage E_{AB}.

The current in transformer *2* is the resultant [illegible] in Fig. 1054 (c) and leads the voltage E'_{BC} by θ_2 degrees. This gives the secondary currents their phase relation and magnitude for transformers 1 and 2. For all practical purposes the primary currents are 180 degrees from the secondary currents and their magnitude is that of the secondary times the ratio of transformation. The secondary full-load voltages can be obtained from Fig. 1064 (a) by drawing in the voltage drop due to the resistance and reactance of the transformers as follows: Considering transformer *1* which carries the current I_{AA1}, the resistance drop is in phase with the current and is represented by I_{AR}. The reactance voltage I_{AX} is 90 degrees ahead of the current as shown. The impedance voltage I_{AZ} is the resultant of I_{AR} and I_{AX}. The impedance I_{AZ}, subtracted vectorally from the no-load voltage E'_{AB} gives the full-voltage E_{AB}. By the same method the full-load voltage E_{BC} is obtained. The full-load voltage E_{CA} across the open phase of the delta is minus the resultant of the full-load voltages E_{AB} and [illegible] as shown. [illegible]

1055—Armature Reaction—Are the methods of calculating demagnetizing and cross magnetizing turns on direct-current armatures, given in text books, used by designers in practice? P. C. (RHODE ISLAND)

Where detailed calculation of armature reaction in direct-current machines is desired, the numerous methods offered in text books and periodicals will be found generally satisfactory. In practice, however, where the engineer's time is an important factor, resort to any lengthy calculation is seldom necessary. Test results on a given line of machines give sufficiently reliable data on which to predict action in new designs. R. H. T.

1056—Over-Load Relay—In cases where over-load relays are used for operating a circuit breaker with but one trip coil, as shown in Fig. 1056 (a), what happens to the current in the middle wire of the secondary

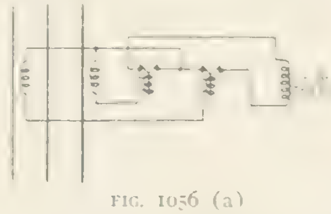


FIG. 1056 (a)

system during a three-phase short-circuit on the line? What effect will this condition have upon the series transformers? D. A. M. (ONTARIO)

Standard apparatus requires the use of two trip coils, but the scheme shown in Fig. 1056 (a) would probably operate with satisfaction. Consider that both relays have opened their contacts on the occasion of a three-phase short-circuit on the lines. No current can flow in the middle wire of the secondary system, and all current must flow around through the trip coil and the two transformers in series. This would mean that there would be a large component in each transformer, 60 degrees out of phase with the normal transformer current, which component would, of course, run up the magnetization of the iron to a rather high value. B. H. S.

1057—Polyphase Motor on Single Phase—We have a three-phase delta connected motor on the hoist of a ten ton crane. The operator was hoisting and one fuse burned out, allowing the motor to run single-phase. When the hoist block neared the drum the operator, instead of placing his controller on center, reversed it and the block continued to hoist and broke the cable. Please explain the cause of this. W. H. M. (OHIO)

A single-phase induction motor has inherently no starting torque from rest and when once started by external means will run equally well in either direction of rotation, depending upon which way it is started. In the case in question, the motor, which was running at normal speed, continued to run in the same direction regardless of the reversal of the two leads. When one considers that in this case the current supplied is straight alternating, *i. e.*, simply reverses in direction, it is evident that reversing the two leads produces no change in the relations existing between the direction of the current supplied and the coils themselves. This can be verified by running any polyphase motor light and pulling off one phase and then reversing the two remaining leads. A. M. D.

1058—Wattmeter Indications—In checking our switchboard indicating wattmeters with a portable indicating wattmeter, we find that as the load increases the reading of the switchboard meter does not increase in the same proportion as that of the portable meter. Both meters register correct zero at no load and the current and voltage ratios are the same. Will you kindly advise what means can be employed to correct this discrepancy without taking all the meters down and shipping them to the manufacturer? [illegible]

The portable and switchboard meters should be connected with current coils in series and voltage coils in multiple on the same set of transformers. If their readings are not then in the same proportion at different loads, one of them must be out of adjustment. The calibration of the portable meter should then be checked. If it is found to be correct the switchboard meter should be adjusted to agree with it. H. B. T.

1059—Cable Troubles—We have had trouble with the breaking down of the insulation between the lead sheath [illegible]

1 000 000 cir. mil lead covered cable at the end leading from the generator to the oil switch. Will cable bells placed at both ends prevent such trouble? Should lead sheath be grounded on a 2 300 volt, two-phase, three-wire 1 000 000 cir. mil lead-covered cable leading from a 2 500 k.v.a. generator to the busses? If so, what size ground wire should be used and what precaution, if any, to prevent a short-circuit in case a breakdown occurs between conductors and lead sheaths? A. L. J. (PENNA.)

The use of cable bells on both ends of the cable will probably eliminate breakdowns as they are designed for this particular purpose. Leadsheaths such as described above should be grounded with a 1-0 to 3-0 conductor from the lead to ground. This size conductor will carry as much current as the cable sheath, temporarily, and should be sufficient to clear the difficulty by opening the station circuit breakers without allowing any dangerous rise of potential of the sheath. A. F. H.

1060—Mercury Arc Rectifier—Kindly give a general method for determining the distance necessary between the electrodes in the mercury arc rectifier for various voltabes. S. H. C. (IND.)

The distance between electrodes has comparatively little to do with the rectifying voltage. The total length of the vapor path is a considerable factor and the cross-section of this path has still more to do with the rectifying power. No rule can be given, as the temperature of operation, the volume of the vacuum chamber, the amount of rectified current, the condition of the magnetic circuit and other factors all affect the matter. See article on "Theory of the Operation of Mercury Rectifiers," in the JOURNAL for June. 1912, p. 561. R. P. J.

1061—Starting Synchronous Motor—Why is it not possible in starting a synchronous motor of say 1 500 horse-power to close the starting switch, which circuit contains the necessary resistances and then after the machine has attained its rated speed close the running switch connecting the motor directly to the line and then open the starting switch without damaging the switching apparatus. H. E. M. (MO.)

If the motor is started by connecting it to the line voltage with a resistance in series, which is short-circuited on the running position, there will be no objection to the above procedure. Such motors are, however, almost always started from low voltage taps on the transformer secondaries, and in such a case the procedure outlined above would short-circuit part of the secondary winding, probably damaging the transformers. C. R. R.

1062—Definition—What relation exists between the British Board of Trade watt and the standard or international watt, also what is the British Board of Trade definition of a horse-power expressed in watts? F. C. W. (MICH.)

The British Board of Trade watt and the standard or international watt are the same. The British Board of Trade horse-power is equivalent to 746 watts. J. S. P.

1063—Phasing Out Transformers—In Fig. 1063 (a) is shown a diagram of connections which showed some peculiar results when the phasing tests were made before connecting the two transformers in parallel. The transformer shown connected to the bus was in service, feeding over-head and under-ground lines which supply small motor and lighting customers. The customer's transformers on these lines transform the voltage down to 230 volts. The middle points of the low tension side of these transformers are grounded and the customers receive power at 115 volts, obtained between these grounded middle points and either of the outside lines. The 2 300 volt lines are not grounded. The transformer shown not connected to the bus is a new machine, and the peculiar conditions were found when the phasing tests were made before connecting this transformer to the bus. In operation, a regulator is used with this transformer, similar to the one used with the transformer already in service. However, in this particular test, due to some trouble found in the regulator, it had been taken out of the circuit altogether. Denoting the lines coming from the new transformer as X_t, Y_t, Z_t, and the bus as X_b, Y_b, Z_b, the following data were obtained:

Voltmeter connected between	Volts
X_T and X_B	1
Y_T and Y_B	0
Z_T and Z_B	0
X_T and Y_B	2880
Y_T and Z_B	3810
Y_T and X_B	2800
Z_T and Y_B	3520
X_B and Y_B	2200
Y_B and Z_B	2280
X_B and Z_B	2280
X_T and ground	1100
Y_T and ground	1010
Z_T and ground	1100
X_B and ground	1180
Y_B and ground	1310
Z_B and ground	1416

It is seen that apparently the two can be thrown in parallel; that is, that the delta representing the voltages of the two seem to coincide. How is it possible to get such high values of voltage when taking the cross voltage readings, such as X_t to Y_b, Y_t to Z_b, etc. It is seen that the voltages to ground are considerably different for the transformer and the bus. The voltages for the transformer are too small to locate a neutral in the center of the delta, while for the bus they are too large. What is the cause of this? There is no electrical connection between the transformer and the bus. W. C. M. (MICHIGAN)

The reason for these apparently inconsistent results is that the low tension windings of both transformers are insulated from ground and from each

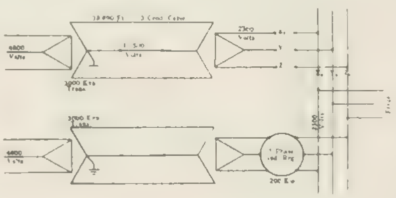


FIG. 1063 (a)

other. Under these conditions the capacities of the two secondaries together with the switches to which they are connected are almost certain not to be the same, and therefore the voltages to ground will not be the same. In other words, the two secondaries will be floating at different potentials above ground. In order to get consistent polarity measurements, one terminal of one transformer must be connected to the corresponding terminal of the other transformers: for example, connect Z_t to Z_b. After this is done the various measurements across the different terminals will indicate at once whether the polarity is correct, and if it is not, a diagram can easily be made out showing what changes will have to be made to make the polarity right. See article on "Determination of Polarity of Transformers for Parallel Operation," in the JOURNAL for July, 1912 p. 613. W. M. M.

1064—Idle Coil in Generator Armature—Can one conductor of a coil be cut out of a 909 ampere, 550 volt, lap wound railway generator armature without causing trouble? The machine has ten poles, about 28 coils of three conductors each per pole or about 84 commutator bars per pole. The two ends of a conductor are joined to adjacent commutator bars. C. W. F. (OHIO)

A lap or parallel wound armature can be compared to several generators connected in parallel. The sets of coils connected in series between every pair of brush arms form distinct generating circuits which are all connected in parallel between the two brush stud busses of opposite polarity. When two or more generators are operating in parallel to supply current to a line and the voltage of any one is reduced, that one tends to motor. Its current reverses and flows to the machine from the others which are still operating as generators. Cutting a single coil out of one of the parallel circuits of a direct-current armature reduces the induced voltage of that circuit, and local current therefore flows in from the other higher voltage circuits just as in the above case of separate machines operating in parallel. Unbalancing the armature circuits by cutting out one coil in this way will consequently set up local currents which will tend to cause excessive local heating. The condition is, therefore, highly undesirable and will probably eventually lead to a burn-out in service. R. H. T.

CORRECTIONS

Near the bottom of page 170, in the JOURNAL for March, 1913, P_s = secondary copper loss, should read "P_s = secondary copper loss running light. Near the bottom of page 180 first column the expression $P_s = \frac{I_n^2 K_r r_2}{4}$ should read $P_s = \frac{I_n^2 K_r r_2}{2}$. The expression for iron loss which follows the expression for P_s should have the same correction made in the expression for secondary copper loss running light. That is, "4" in the expression of P_i should be changed to "2." In the first line under figure 8, second column, page 180, EL_i should be EZ_L. In table X, page 181, the formula for r.p.m. No. 11 should read as follows:

$$\sqrt{\frac{10^2 - 9^2}{5 \times 10}} \times \text{syn. r.p.m. or } \sqrt{\frac{10}{5}} \times \text{syn. r.p.m}$$

In the JOURNAL for April, 1914, p. 228, fourth line above Fig. 4, "S_4" should read "S_2." After the word "remain" in the eleventh line above Fig. 7, p. 229, insert "in operation. Each of the relays at *17*, *18* and *19* should be connected to operate only when trouble occurs in the machine which it controls."

THE ELECTRIC JOURNAL

VOL. XI JUNE, 1914 No. 6

Editorial Resume

In this issue are included a number of articles on subjects of a purely commercial nature. The contributions by Messrs. Lloyd, Burnett, Perry, Weaver and Jones present the results of the experience of some of the most enterprising companies and most widely known men in the industry, on a subject that is of vital interest to every central station man. Electrical merchandising, as emphasized by Mr. Jones, has passed beyond the stage of selling apparatus at cost and relying upon the sale of current for the profit. The present-day electric shop is as fully able to stand on its own feet as any other department of the company. This policy, by permitting a fair profit to electrical dealers and department stores, enlists the coöperation of these establishments in pushing the sale of domestic power consuming devices. Equally pronounced is the modern tendency in pushing the sale of current. Equitable rates and reliable, continuous service are admitted to be essentials which must be available before the commercial department can be expected to do consistent work. A careful study of the needs of power prospects, conducted on an engineering basis and with the conclusions rendered from an unprejudiced standpoint, forms the foundation for the solicitation of power business with a number of companies, and in fact a spirit of fair dealing may be taken as typical of the industry as a whole. This is reflected in the work of the National Electric Light Association which, through various committees, is striving to keep in close touch with the general public, as well as with the Public Service Commissions, in order to conserve the best interests of the whole industry.

The success of this policy is attested by the remarkable growth indicated by the advance census statistics recently made available, which show an increase of 252 percent in central station income during the ten years from 1902 to 1912. On the basis of an average increase of 25 percent per annum, as represented by the above figures, the gross income for 1914 would be in excess of $450 000 000. The capacity of generators in 1912 was 5 135 000 kilowatts, representing an increase of 324 percent, and the total output from these generators was 11 503 000 000 kilowatt-hours, or an increase of 358 percent. This indicates an increase in average station load factor from 23.6 percent in 1902 to 25.6 percent in 1912. The total horse-power of motors connected to central station lines in 1912 was 4 131 000, a truly remarkable increase in ten years of 843 percent.

Commercial features are assuming especial importance since the development of the various types of apparatus has advanced to such a point that the central station man has only to select, from the wide variety of new and improved apparatus, that which best fits his individual needs. With respect to the small power consuming devices intended for general use, such as those treated in the articles by Messrs. Lester, Garlits, Peale, Carpenter, Wicker, Brackett and Wible, this statement is literally true. With respect to power station and distributing apparatus of the type treated by Messrs. Hardin and Henderson, Mahoney, Reed, Roosa, MacGahan and Taylor, no small amount of engineering ability is required in the selection of the most suitable apparatus, although practically all of the apparatus described has been developed to such a condition of ruggedness and fitness for the service intended that the maintenance costs are reduced to a minimum. This is especially true of the watt-hour demand meter described by Mr. Boddie.

Several of the contributors to this issue have emphasized the supreme importance of reliability of service and good voltage regulation; and the skill and thought necessary to the successful attainment of these requisites is well illustrated in the articles by Messrs. Imlay and Jenks, which present features of interest connected with the operation of the Canadian Niagara Falls Power Company and the West Penn Traction & Water Power Company. Both of these systems have enviable reputations for continuity of service under exceptionally severe operating conditions. The West Penn problem is especially difficult in this respect on account of the wide area of territory covered with a type of construction which, for the most part, is in the nature of a distributing system rather than of especially designed transmission lines.

A type of central station problem which cannot be solved by the purchase of apparatus, but requires rather the expenditure of gray matter, is illustrated by the pole setting derrick devised by Mr. LaDue and presented by him in this issue as a contribution to the industry. The most prominent characteristics of this derrick are its ready portability, its ruggedness, and the readiness with which the boom can be shifted from one side to the other, or lowered when passing overhead wires.

The Work of the National Electric Light Association in 1913

J. B. McCall
President
National Electric Light Association

THE growth of the National Electric Light Association is from about 3 000 in 1909 to nearly 14 000 in April, 1914, the gain being due chiefly to the activity in recruiting employees into Class B, and Company Section development. The Association, as nearly as can be estimated, represents 90 percent or more of the $2 500 000 000 capital in the industry, earning an annual gross revenue of about $450 000 000.

The Association is fostering the geographical or state section idea, never invading a state where there is an active local association at work, but seeking to create such bodies where non-existent. It does, however, favor the group geographical plan—as in New England, the Northwestern and Southeastern Sections—for two good reasons. One is that small and relatively weak state bodies are merged into large and powerful groups, and that in some states the financial policy of plant merger has gone so far that only two or three large companies at best are left to form a single state section. The other reason is that it is far easier and better, therefore more economic, for the parent association to deal with a few large group associations than with thirty or forty smaller ones. One obvious objection to the group plan is that while the small company manager thus has an association nearer to him in some senses, he is still without the opportunity to attend a meeting each year in his own state, as usually the annual convention goes from state to state each year, and the distances are frequently quite considerable. "Going to conventions" is a distinctively modern habit, and would not be indulged in so universally if it were not an educational factor that pays. It is remarkable, however, that many owners and managers of small companies never get around to conventions, although they do embody the "get together" "central" idea in their own local work.

The Company Section idea is slowly pervasive, although the fact that there are still less than fifty such sections shows that the benefits obtained thereby to companies and employees are not as yet fully realized. This is emphasized by the fact that one or two company sections have crumbled away. One of the reasons seems to be the relatively short supply of local talent to draw on. A company may soon use up its available material if it has not a very large organization, and many of the best men have neither the time, desire nor ability to prepare papers or address an audience. Hence, during the past two years, the Association has thrown a great deal of weight on its new Lecture Bureau, which has elaborated a technical and instructive programme of papers and lectures by well known men, available without cost to any company section, on request. This is being availed of more and more, and bids fair to do much in building up old Company Sections and creating new ones. In addition to encouraging this educational work we find that companies tend more and more to use the section as a means of getting in closer touch with their employees, in a social and friendly way. The Company Section is the cement which binds together the personnel of the industry.

The work of the Association is evidenced in many ways, largely by its literature:—Annual Convention in four volumes of Proceedings—2 000 pages; the monthly Bulletin of approximately 80 pages each issue, one half of which is Question Box; Bulletin of its Rate Research Committee, devoted to recording data on rates, regulations, etc., 12-16 pages weekly; Commercial Digest of Commercial Section, and numerous pamphlets to help the sales organization. The Association files the rates of several hundred member companies by states and by size of community and distributes the data to help member companies in arriving at equitable and fair local tariffs. The Association also issues the Meterman's Handbook, containing 1 200 pages, of which several thousand copies have been sold; also the electrical Salesman's Handbook, now under revision by the Commercial Section, and of which 10 000 or 12 000 copies have been issued.

Individual reports of standing committees are in constant demand throughout the year. The meter report of 1909 is still in demand, as well as the overhead line construction report. The Committee is about to issue a Standard Overhead Line Construction Handbook of about 1 000 pages.

The Association was the first to compile and analyze Public Service Commission laws and requirements in a volume covering Massachusetts, New York and Wisconsin, and is one of the few institutions filing the rulings and reports of all such commissions. It has also printed and circulated the Code for Electricity Meters in large numbers in 1913.

The Association organized the Resuscitation from Shock Commission and has now distributed probably 250 000 copies of the chart and booklet embodying rules laid down. This work is now being supplemented and broadened by that of an Accident Prevention Committee, which is issuing booklets, placards, rules, recommendations, etc., as

to means for organizing station Committees of Safety, for preventing accidents, for ensuring greater care on high tension lines and apparatus, etc.

During the last few years the Association has experienced an extraordinary demand for its literature, with many inquiries as to its membership, from abroad. A constitutional amendment was made this year opening the membership and literature to all foreign companies at a flat rate of $20. Although no official attention was directed to this, 21 foreign companies are now members, and it is intended to call the attention of all the larger companies to the fact that the privileges have thus been thrown open to them on a purely fraternal basis.

Such matters as Accident Prevention and Resuscitation fall under the head of Welfare Work, but there are many other items which should be included, such as Company Sections, Lecture Bureau, etc. The chief item, however, is the work of the Public Policy Committee in framing and recommending to the member companies a complete system or plan of sick relief, accident relief, death relief, saving funds, long service annuities, profit sharing, employee stockholding, etc.—all of this being the first essay of the kind on the part of any such large representative body and anticipating liberally much of the peremptory legislation of the times.

It may safely be claimed that at no time, nor in any respect has the Association placed its member companies in antagonism to recognized authority, although it has often led and coöperated with them in opposition to measures and tendencies that were deemed obnoxious to the public good or detrimental to a service whose only reason for existence is that it meets a public necessity and satisfies some of the most urgent demands of modern civilization for better light, cheaper power, greater safety, lessened manual labor and healthier homes, offices and factories. The Association has prepared and standardized various definitions, as for instance the 2 000 c-p arc, has issued standard forms of franchise, standard conditions for sign lighting in streets, standard line construction, etc. One of its presidents, Mr. Samuel Insull, in an address delivered some years ago, was probably the first public utility manager to advocate regulation; and at every stage the Association has closely coöperated in every way possible with the Commissions. At the Seattle Convention, in 1912, every Public Service Commission on the Coast was invited, and at the Chicago Convention, in 1913, every Public Service Commission in the country was invited to attend or send representatives to participate. The United States Bureau of Standards sent one of its chiefs to discuss electrical hazards and a representative of that Bureau is an active member of the Accident Prevention Committee. At practically every convention of an affiliated State Section—now including more than half the country—the State Commissioners are invited to attend, and some of them generally participate.

In one special direction the Association has sought steadfastly to educate the public, viz., in regard to municipal ownership. The bedrock principle of the National Electric Light Association has been the private operation of public utilities, and the elimination of the vicious principle of putting money raised by taxation into intricate, technical mercantile enterprises. All the experience that can be studied in available data justifies such a view, and the present reaction in Europe may be regarded as a vindication of the stand taken by the Association since its foundation.

The Association during its early years was essentially an engineering body. The rapid improvement in electrical apparatus of every nature and the need of the Association's members for the most modernly equipped generating and distributing systems, compelled betterments of various nature in rapid and swift succession, the result being that the companies themselves were forced to carry a heavy financial burden because of expensive obsolescence. These rapid changes are going on even today, and in no other industry does this same item of obsolescence attain such proportions or wear such a serious aspect. Association member companies, however, have never tried to evade or postpone the investments necessary to meet the new conditions as the art advanced. They have, on the contrary, coöperated in every movement toward perfection in electrical equipment of every nature. Long before the general public was interested in underground wires the Association offered a gold medal for the best paper on the subject. With various engineering bodies in all fields it has joined hands to secure higher engineering ideals, and at this very moment is an active sharer in the efforts to secure a higher standardization of electrical apparatus. On all its engineering committees, representatives serve from professional engineering societies and from manufacturing companies, thus ensuring a mutual understanding directed to the common good; but it must be clearly understood that the Association protects the interests of what is undoubtedly the largest group in the world of the purchasers of electrical machinery, apparatus and supplies.

The Association has done more perhaps than any organization of its kind to establish and maintain the market value of electrical securities, and protect the interests of the investor by fighting "raiding," piracy, and competition of an unnecessary character, by insisting on the essential monopoly of the service, subject to proper control and regulation. Time and again the spokesmen of the Association have voiced this axiom. Time and again they have warned against inflated securities, while insisting on the rates that could bring into the industry the new capital constantly needed. The matter of just and equitable rates is a leading question of the day, and vital to

central station enterprise. The Association has, through all the "conservation" movement, endeavored to give it a constructive form. Three years ago it summoned a conference on the subject when for the first time in the presence of the then Secretary of the Interior, Mr. Walter Fisher, voice was given to the aims and objects of the Association for the common good. The hydro-electric section has steadily bent its efforts in this direction of "use" of energy from water now flowing idly to the sea. The Association has done all it could to help in the protection of forest areas, and natural watersheds, has advocated the indeterminate franchise, inviting and protecting capital, and has gladly coöperated with every other national society having kindred objects.

Two of the newer directions in which the Association has bent its energies during 1913-14 has been to cultivate closer intimacy between the colleges and universities of the country and the central station industry. A new committee under the chairmanship of Mr. John F. Gilchrist is dealing with this subject, and there is every indication that its work will be productive of benefit, both in bringing the professor and the student into direct relations with the central station and enabling the central station president or manager to present before the classes in college a sane view of economic conditions that control the problems under which the electric lighting industry has to be carried forward. The other latest item of importance just referred to is the effort of the Association to interest its members in a larger use of the electric vehicle by the postoffice department. In this work it has worked side by side with the Electric Vehicle Association in a country-wide campaign, and has invited the coöperation of every member company to see that, particularly in regard to the parcel post system, the government "does it electrically."

EVERY PUBLIC SERVICE POWER COMPANY operating in a progressive community is in a position to realize the necessity for the most advanced commercial methods for increasing business. The following five articles, by well-known central station men, indicate some of the methods of load building which have been found most effective in their particular communities.

Load Building in Large Cities

E. W. Lloyd
General Contract Agent
Commonwealth Edison Company, Chicago, Ill.

Fundamentally I think it is absolutely essential to the success of any central station sales organization that they have a good rate system to work with. It is necessary that the employes of a sales department have confidence in the product their company offers to the public. No salesman is capable of closing business unless he believes that the article he has to sell is good as well as reasonable in price.

Next in order comes reliability of service. No matter how able a salesman you may have or how good your rate system may be, if your service is bad you will not accomplish the best results.

The company having seen to it that these two important items have been well arranged, it becomes necessary, in a large company, to have a sales organization sufficiently diversified in its make-up to handle a great many different schemes for getting new business. Formerly in a large community it was considered advisable to have the city cut into districts for power and light only, having men put in these districts to handle these two branches of the business and, in addition to these district men, a very few general men for handling special propositions. As time went on it became evident that the central station companies must secure larger and larger business as their rates reduced. This necessitated the hiring of more capable men to work in districts. Residential business in the larger cities is not difficult to secure where the companies' lines are freely installed. Lowering rates and highly efficient incandescent lamps have contributed to this result, so that the district salesman is compelled to transfer his energies to other classes of business that are not so easy to secure.

Today in the up-to-date large company the work of getting new business is becoming very highly specialized. Experts on large business handle a few industries, and by so doing become highly proficient in presenting central station propositions to customers. These specialists are divided into small lighting salesmen, large lighting salesmen, small power salesmen, large power salesmen, sign salesmen, rental equipment salesmen, illuminating engineers, merchandise salesmen, etc. Other men are developed to handle office building and similar business, who understand thoroughly the mechanical and lighting equipment of such buildings, consumption of energy required by the different apparatus in the building, etc. Taking it altogether, the men doing the more important work require some technical education, either secured through a university or in some other manner. The grade of men employed as salesmen today is much higher than it was a few years ago, and I believe that the future salesman will be required to be a better all-round man than even the most efficient central station salesman of the present day.

The commercial end of the central station business has come into its own within the last few years, and everyone realizes the importance of a well organ-

ized highly technical sales machine. Such a machine spells success to the central station employing it.

Supplementing the work of the sales organization I might add that of the advertising department. The work of these two departments is necessarily very close together. Advertising in the daily press, local publications of value, illuminated bill-boards, street cars and circular letters add very materially to the work of the sales department. In fact, in the large central station the amount of money spent on judicious advertising can approach the amount of money spent for salesmen's salaries with good results.

Building Big Business

Douglass Burnett
Manager Commercial Department
Consolidated Gas, Electric Light & Power Company, Baltimore, Md.

THIS ARTICLE OUTLINES the different phases of a modern central station company's commercial activities, all of which must receive due recognition, exploitation and encouragement on the par: of the financial and managerial authorities who have the responsibility of providing the means whereby the business may be conducted, and who will reap their share of advantages, not only from the profit which will result from a healthy, growing industry, but in the sense of having fully and well performed their duties in the development of their local communities.

At the outset we assume that the central station and its distribution system has been established to serve the electrical needs of the community. The first requisite in building up a business is a system of carefully prepared and explicitly stated rates to meet the varying service conditions.

RATES

The commercial rate schedules of the company must be made up basically of the following items:—

1—Rates for transient or temporary service for occasional requirements. These rates are for such short-term uses as the supply of fan service during the warm weather season, for summer cottages, for amusement parks, for temporary decorative illumination during times of celebration, for houses temporarily served during periods of display in order to interest new tenants or purchasers, old houses wired and in the hands of real estate agents, stores occupied during temporary sales seasons, as for the Christmas holidays.

2—Rates for the ordinary run of small commercial requirements, constituting the service to a large majority of central station customers, usually for demands of 50 kilowatts and under for both lighting and power. These rates are for the usual run of residences, places of business and small manufacturing service to individual tenants of ordinary buildings, and are intended to apply to the permanent lighting and power requirements of the occupants of ordinary properties. Specific provisions must be made under this class of rates for such special service as is represented by the charging of automobiles during night hours, and the supply of customers using the major portion of the service at times outside of the station peak hours on days at any time of the year or especially during the summer time when the station peak does not occur. Modifications of these rates in the shape of separate or subsidiary schedules must be provided to care for those classes of business where the service may readily be controlled and operated during predetermined hours of use, such as electric signs and building display lighting, the rates being, in such cases, greater than the usual meter rates by an allowance covering the cost of patrol service, the delivery, installation, inspection and maintenance of lamps and lamp renewals by the central station, rather than by the customer, and the installation and use of any special equipment, such as master-key switches, time switches, flashers and the like. The usual rates for the retail service must provide for the differentiation between lighting service, wherein the use of current is dependent upon the number of hours per year of artificial daylight depending upon the sun, and the use of power which is usually required at all times, during fixed working hours throughout the year. These rates may be so devised and fixed that these different lighting and power requirements can and will be cared for from the same service and meter connections and from the same meter, involving, however, differences in the rates which encourage the use of the long-hour, steady power service which offers low production cost advantages to the central station. These rates may be coupled with provisions as to the extent to which the company will make investment in extensions of its distribution system to supply desirable business on the basis which is outlined in the schedules.

3—Rates for industrial service with demands of, say 50 kilowatts and over, for customers using service from the general distribution system of the company, and hence using the ordinary classes of service available through the territory. These rates must provide for both lighting and power service, since factories must be equipped so that they may operate during the set working hours common to the industry, irrespective of the presence or absence of natural daylight. These rates must be so fixed and determined as to properly care for the ordinary lighting requirements, with the resulting usual low load factor, in such a way as to not interfere with the application of the low rates earned by the power installation operating during the fixed hours, which latter are largely independent of the season of the year. Ample inducement

must be offered in the rates to encourage the use of overtime service to the maximum possible extent, with the intention of securing the highest possible load factor. These rates must also be such as to permit companies using three-phase service for feeder distribution and single-phase service for house-to-house distribution, to enable the bringing of the three-phase service for large motors from the feeder point to the customer's premises on proper terms, and to provide also for the supply of the special and extra transformer, meter and service equipment, necessary to provide for the three-phase service to the power installation. These and the following industrial schedules must necessarily eliminate any care of the customer's installation, or any furnishing of any part of the equipment utilizing the service, or renewals therefor, such as the incandescent lamp equipment or renewals, arc lamps and their care, or any inspection or maintenance of the power equipment.

4 *Rates for industrial service when supplied from the high-tension system of the company.* These rates should differ from the preceding industrial rates to the extent represented by the saving in investment in distribution system and, owing to the special character of all equipment used for the supply of these customers, should be such as to encourage the use of electric power industrially with the highest possible load factor, with the intention of approaching as nearly as possible to a continuous load throughout the 24 hours of every day in the year.

5 *Rates for industrial service when supplied without distribution investment on the part of the company.* These rates must differ from the preceding rates to the extent of eliminating the return on the investment in all distribution equipment of any character, and should provide an adequate return on the investment and operation from a generating standpoint only, leaving all distribution and maintenance to be provided for independently of the rates by the customer or by separate charges to the customer.

THE COMMERCIAL DEPARTMENT

Having established an adequate set of schedules of rates for the service, the second requisite to the growth of the business is the establishment of a commercial department. This department must be adequately organized to promote, by advertising and by personal solicitation on the part of salespeople specializing on their own branches of the work, the use by the different classes of customers of the different classes of equipment that will utilize the service, and to promote in every way satisfaction with the use of the service. The commercial department must be organized into sub-departments for the sale of power and of light and for attention to questions of general service, for advertising and for maintenance of stores and offices for the conduct of the work with customers.

As one feature of the commercial department, the industrial power department must be formed to sell power, to study possible new business among all lines of industries, to promote and encourage the establishment of new industries, to assist and advise with customers as to the proper equipment to meet their industrial requirements, and to specify and oversee the correct installations for utilizing the electric power sold under the industrial schedules.

The smaller classes of business, such as residences and stores, must be adequately exploited by advertising and personal solicitation, and the same plan of advising the customers as to the equipment to be used and coöperating with the customer in devising, purchasing and installing the equipment to the smallest detail must be prosecuted as is true in the case of industrial service. Here we find some radical improvements in central station exploitation in the development of the past few years where merchandising plans have been adopted by lighting companies intended to acquaint customers with and to secure the use by customers of all classes of current-using equipment, including wiring, fixtures, appliances and small motors.

The conduct of the work of the selling and engineering organization of the commercial department, working with the prospective customers to the end of having the customers install standard electrical equipment of all kinds, must be supplemented by adequate plans and methods for determining upon the identity of possible users of the service. An industrial survey, showing the possible uses of electric power in all existing manufacturing establishments should be made by the industrial power department to the end that the power requirements of all customers not using the service of the central station will be made, and that standard equipment needed for the use of power by them, may be known, estimated upon, sold, installed and used. Likewise, it is important that every occupied building, representing a desirable customer, should be sought out, made known and canvassed, and its electrical needs laid before the occupant in an effective and satisfactory manner to the end that such equipment will be recommended to him, sold, installed and used. Likewise, it is equally necessary that adequate provision be made for the installation by owners of new buildings, and for the specification by the architects for such owners, of the proper electrical equipment for such buildings, and a carefully prepared plan of canvassing for and selling the necessary equipment for such buildings must be worked out and conducted by those who assume the responsibility to produce new business among this class of users.

Parallel with all of this, an industrial survey of the supply and demand of goods of local manufacture and use is desirable in order to determine the variations in supply and demand, and the relations between them. The purpose of this survey is to learn whether the local consumption of manufactured goods is adequately measured up to by the local manufacturing facilities for such goods; likewise, to determine where there is a local manufactured surplus of such goods that may be advantageously disposed of outside the community itself, and steps must be taken by some

organization to find a foreign market for such goods. Such an industrial survey leads to a clearer understanding of the possibilities in the way of local manufacturing and opens the way to a means whereby such facilities can be established.

For the further encouragement of home industries, it has been found advisable, in certain cases, to provide industrial buildings in which small manufacturers may rent space without the necessity of capital investment in real estate, buildings and certain branches of supplying equipment which may be used in common. Such industrial building facilities best serve their purposes when so conducted that there will be accepted as tenants only those who require more than a certain minimum amount of space and less than a certain maximum amount of space, so that when the manufacturer's business has grown to a certain point, he may take his full responsibilities of establishing himself in his own quarters as a permanent manufacturing enterprise of the community.

This, in brief, covers the whole scope of the work of the commercial organization for the promotion of central station business, and in those cases where a systematically developed plan for conducting the business along these lines has been established, the results in the way of efficient conduct of the work have been truly remarkable. The best results have been secured where special attention along the above lines has been directed to the development of those classes of business where the most favorable conditions apply. For instance, some central stations have found it advisable to make current monthly analyses of their output and station generating conditions to the end that the best diversity factor will result from the new business secured, as well as the best load factor, and cases have been known where, as a result of thorough intensive work, the load factor on central station systems has been increased from a figure of the order of 25 percent to a figure of the order of 50 percent annually, and where the daily load factors have risen to some 70 percent without considering the supply of such large units of power as are represented by the local traction systems. In these cases, the current supply has been entirely to the individual persons, firms and corporations doing business in the community, rather than public service corporations and street railways.

Finally, the third requisite is good service, and here is the special field of the construction and operation engineer. All the work of the commercial department will be undermined, if the service is not maintained at the highest standards. A well-meaning, courteous, prompt and efficient set of men having to do with the extension of lines and the connection of new customers, the setting, testing and reading of meters and repairing of line trouble is just as necessary as proper attention to the maintenance of uninterrupted current supply and good voltage regulation on the lines. Regular inspections of physical and voltage conditions on the lines must be made, and attention must be given to the adoption and enforcement of proper rules for standard electrical equipment, of service and meter wiring, as well as customer's wiring, looking to good, workman-like and safe construction.

SUMMARY

While this short review is not intended to, and probably will not, give glowing and interesting illustrations of the working out of these policies, yet it is of the greatest and deepest importance to the development of our central station industry that, in any case the work of the central station be carefully planned, organized and carried out along these lines. Specific variations due to local conditions or due to the judgment and opinion of those locally responsible are to be considered and are quite permissible. Owing to special natural resources in a certain community, or the large development of certain special classes of customers, it is to be expected that the special needs of such local developments will be reflected either in a large development along particular lines or in special well-equipped organizations for the exploitation of particular classes of service. Thus, we find some central stations in the mining territory will supply the major part of their service for mining requirements, and in Western sections of the country, irrigation will be a prominent feature of the company's work. In others farming and in still others general urban conditions, consisting more or less of large local manufacturing interests, office buildings and residential service are the features.

Securing Power Business

L. P. Perry
Power Engineer
The Narragansett Electric Lighting Company

THE Narragansett Electric Lighting Company has found that its most successful efforts in securing additional power customers have been at times when isolated plants are about to renew boilers or engines, or will require additional equipment, or have been experiencing unpleasant relations with incompetent plant operators.

This company serves a territory of about 300 000 population, including wonderfully diversified industries. The so-called "power-prospects" are very numerous and it is customary to center efforts on such business as will be the most easily secured, as otherwise a great deal of time and expense could be indiscriminately wasted. There comes a time in the history

of every plant when conditions are most favorable for substituting central station power.

All prospective power users are catalogued with an entry against each, showing the business, the horse-power involved, and the power engineer who has worked upon this prospect. In another file are kept abstracts of all conversations, copies of all letters and all data having to do with prospective customers. In this manner transactions for five or ten years past may be reviewed.

The business is secured with the least possible amount of work. If it is possible to close a contract through salesmanship and conversation alone, it is done. Otherwise, a letter is submitted covering the situation. If, as is frequently the case, the isolated plant owner has no interest in central station power, it is at first possible to do no more than to secure permission to make an extensive examination of the plant, the report of which is submitted, carefully bound in leather. The leather cover frequently has an effect. Obviously it is inappropriate to present a report costing the lighting company from $50 to five hundred dollars in an unattractive paper binder. If this report does not secure the contract it is usually to be found in a conspicuous place on the plant owner's desk for several years after, for it has become his authority on his power plant. When conditions have changed this report reminds him to telephone for the lighting company's power expert.

A stock of several carloads of motors in sizes up to 100 horse-power enables the handling of emergencies with dispatch. Motors are sold on a year's trial when the company is confident that the installation will become permanent.

The foregoing policies have secured about 12 000 horse-power of new business in the past four years, during which time engine salesmen have practically abandoned activities in Providence.

Methods of Load Building

Gordon Weaver
Power Sales Manager
Kansas City Electric Light Company

CENTRAL STATION LOADS are seldom, if ever, successfully built with the new additions secured during a strenuous new business campaign, but the business secured later as a result of such a campaign frequently is both desirable and profitable. In other words, it is the quality of the load rather than the quantity that measures the desirability of new business from a central station standpoint.

The careful training of salesmen we have found to be essential for successful load building. Salesmen who believe that the methods of their company are fair and that the rates for service are just and equitable are the very best kind of load builders. I believe that if central station companies would spend more time convincing their salesmen that their rates were just, and insisting on an honest and straightforward policy, and less time in canvassing and soliciting new business, the results would be infinitely better.

Approximately 85 percent of the contracts for power in Kansas City are made with customers who inquire at the office either in person or by telephone. The other 15 percent of the contracts can be traced either directly or indirectly to soliciting done by men in the Power Sales Department. When an inquiry comes into the office from a prospective power customer it frequently takes a very capable man to make a customer out of the inquirer. We find that courteous treatment and tact, mixed with a little engineering, judiciously applied, will make customers out of more than 95 percent of the inquirers.

The system in general employed in the Power Sales Department of the Kansas City Electric Light Company is the following:—The city is divided into districts with a salesman in charge of each district. It is the business of every man to know personally someone connected in a responsible way with every isolated plant in his territory, regardless of the size of the plant. A large percentage of customers who change over to electric service from isolated plants are those who call up the salesmen in charge of their district for assistance in an emergency until some repairs can be made. In cases of this kind we endeavor to give prompt service and use every effort to see that they are operating with electric service in the shortest possible time. Very few installations of this sort are ever taken out.

We have in connection with our Power Sales Department a capable engineering staff who make engine tests and advise in regard to improving methods of drive and other ways of increasing the operating efficiency of the plant. This work is done gratis, and while it often does not have any perceptible effect immediately, we frequently find that a prospective customer who has had an engine test made on his plant and a set of our plans made up, will install electric drive and purchase his energy from the central station whenever any changes are made in his factory.

We have been particularly fortunate in securing the business of every brick plant operating in the city limits, and a number of the larger packing houses. This business, I believe, was secured on account of the inoffensive aggressiveness of our representatives, the investigations and tests made on these plants, and the fact that someone in authority connected with the manufacturing concerns knew personally one or more members of the Power Sales Department.

Merchandising Methods for the Sale of Appliances

T. I. Jones,
General Sales Agent,
The Brooklyn Edison Company

THE MOST EFFECTIVE modern methods by which progressive central stations sell and encourage the sale of electrical appliances are all embodied and included in one word—"merchandising." The day has passed when the central station felt that it was wise to look upon the sale of appliances purely from the standpoint of additional current consumption. The result of operating appliance departments on a modern merchandising basis has been so gratifying that there is no doubt as to its permanency.

The successful central station to-day merchandises appliances much as a department store might. It buys at the lowest price, takes into consideration every element of cost which enters into the doing of business, and bases its price to the public on the cost of the appliance plus the cost of doing business, with the addition of a liberal profit; high enough, in fact, to permit of special sales at a reduced price; high enough to encourage the development of appliance sales by contractors and supply dealers.

The proper merchandising method includes the use of the right kind of advertising, attractive window displays (frequently changed), and a live selling organization capable of initiating and carrying out ingenious and effective sales plans.

In Brooklyn, the plan of having a special sale each month has proven very successful. The appliance chosen for sale is purchased in quantities at as low a figure as possible and is advertised at a price which, though lower than list, still permits of liberal profit. The use of return post cards, such as those illustrated herewith, has been found unusually effective in these campaigns, and these are enclosed in envelopes with the monthly bills to residences and stores. By this method alone more than 1 300 irons were sold in one month, 700 grills in another, while during the month of February of this year more than 500 vacuum cleaners were sold by mail at a satisfactory retail price.

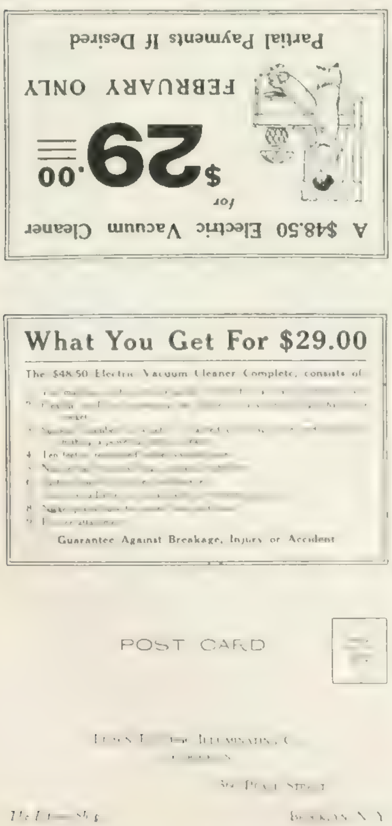


FIG. 1—OBVERSE SIDE OF RETURN POST CARD ADVERTISING A SPECIAL VACUUM CLEANER SALE

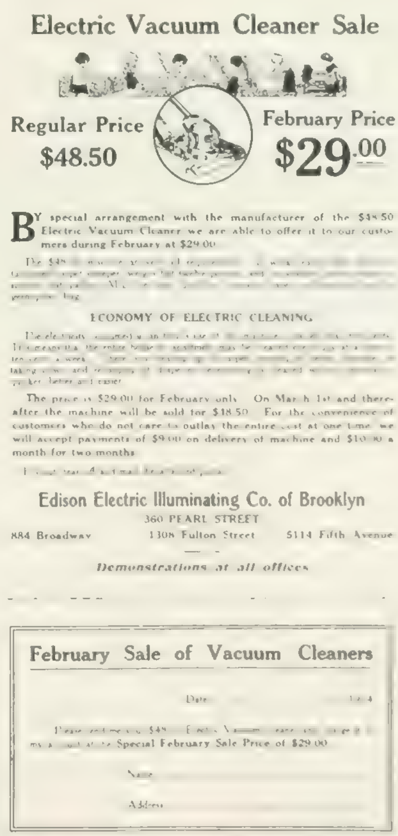


FIG. 2—REVERSE SIDE OF CARD SHOWN IN FIG. 1; THESE CARDS ARE PRINTED IN RED AND BLACK

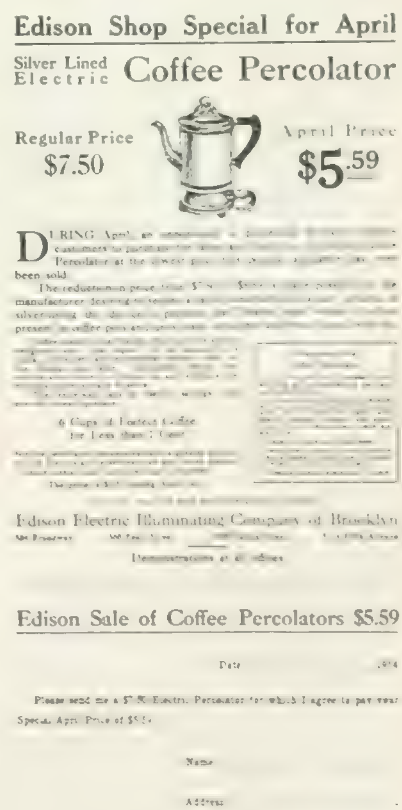


FIG. 3—REVERSE SIDE OF RETURN POST CARD ADVERTISING A SPECIAL SALE OF PERCOLATORS

Some Special Features of The Canadian Niagara Power Company's Plant

L. E. Imlay,

Superintendent,
The Niagara Falls Power Company

FOREWORD—I have been requested to write an account of the power plant and equipment of the Canadian Niagara Power Company at Niagara Falls, Ontario. I realize that the description of a power house, with the enumeration of the number and size of various items of equipment, and the names of the manufacturers, is very dry reading. I propose, therefore, after giving a very brief outline of the history and main physical features of the plant to confine myself to the special features of the plant which have been worked out by our engineers after extended experience of several years in operation and maintenance of the initial portion of this company's equipment and of the plant of The Niagara Falls Power Company on the American side of the river.

THE construction of the Canadian Niagara Power Company's plant was begun in 1901 and the first commercial service was delivered from it in 1905. The plans provided for a building 590 feet long by 110 feet wide, with eleven vertical generating units. The initial installation consisted of three 10 000 horse-power, Francis type, vertical double runner turbines connected to 12 000 volt, 25 cycle, three phase generators of like capacity. This was followed almost immediately by two more units of the same size. In 1910 a 12 500 horse-power double turbine unit was installed and during 1913 a second unit of the same size was installed. These latter units are each equipped with two distinct Francis turbines on the same shaft, having separate wheel cases and separate draft tubes. The total installed capacity at the present time is, therefore, 75 000 horse-power. Elevations of the 10 000 and 12 500 horse-power units are shown in Fig. 2. The power house is completed to its projected size, and foundations for four more units have been prepared. Fig. 3 is a view of the interior of the plant at the present time. The general plan of the wheelpit and discharge tunnel is the same as that of The Niagara Falls Power Company on the American side of the river.

The feeder installation consists of thirteen 11 000 volt, 3/0, three-conductor cables extending from the power house through Queen Victoria Park across the Upper Arch Bridge to the plant of The Niagara Falls Power Company. Two cables are regarded as one feeder and are connected to one set of feeder switches; thus seven feeder switch equipments are required for this part of the service. There are sixteen 3/0, three-conductor cables extending from the power house through Queen Victoria Park to the step-up transformer plant, which is on the hill about one-quarter of a mile from the power house. Eight feeder switch equipments are required for this part of the service. The total output of the power plant, consisting of approximately 75 000 horse-power, is therefore controlled by fifteen feeder switch equipments.

FIG. 1—EXTERIOR VIEW OF POWER HOUSE, SHOWING OFFICE AND CONTROL ROOM STRUCTURE

At the time the first units were installed a switch control board was provided on the main floor of what is now the north end of the power house, this being the only available location for it. When the second half of the installation was undertaken, studies were made for a control equipment for the entire plant, to be located in the center of the power house. This location for the control board, while answering most requirements, had three objections; first, there would be serious congestion of conduits for control cables at the center of the plant where the floor space was already occupied by motor-generator exciters; second, the noise on the main floor; and third, the high temperature experienced in the summer season. The heat radiated by such a large capacity in generators in a single

room of the size above indicated is something to be reckoned with. It was, therefore, decided that the best place for the control room was outside of the power house proper. The forebay roof on the side of the building facing the Falls seemed to be the most feasible location. To carry this out required careful

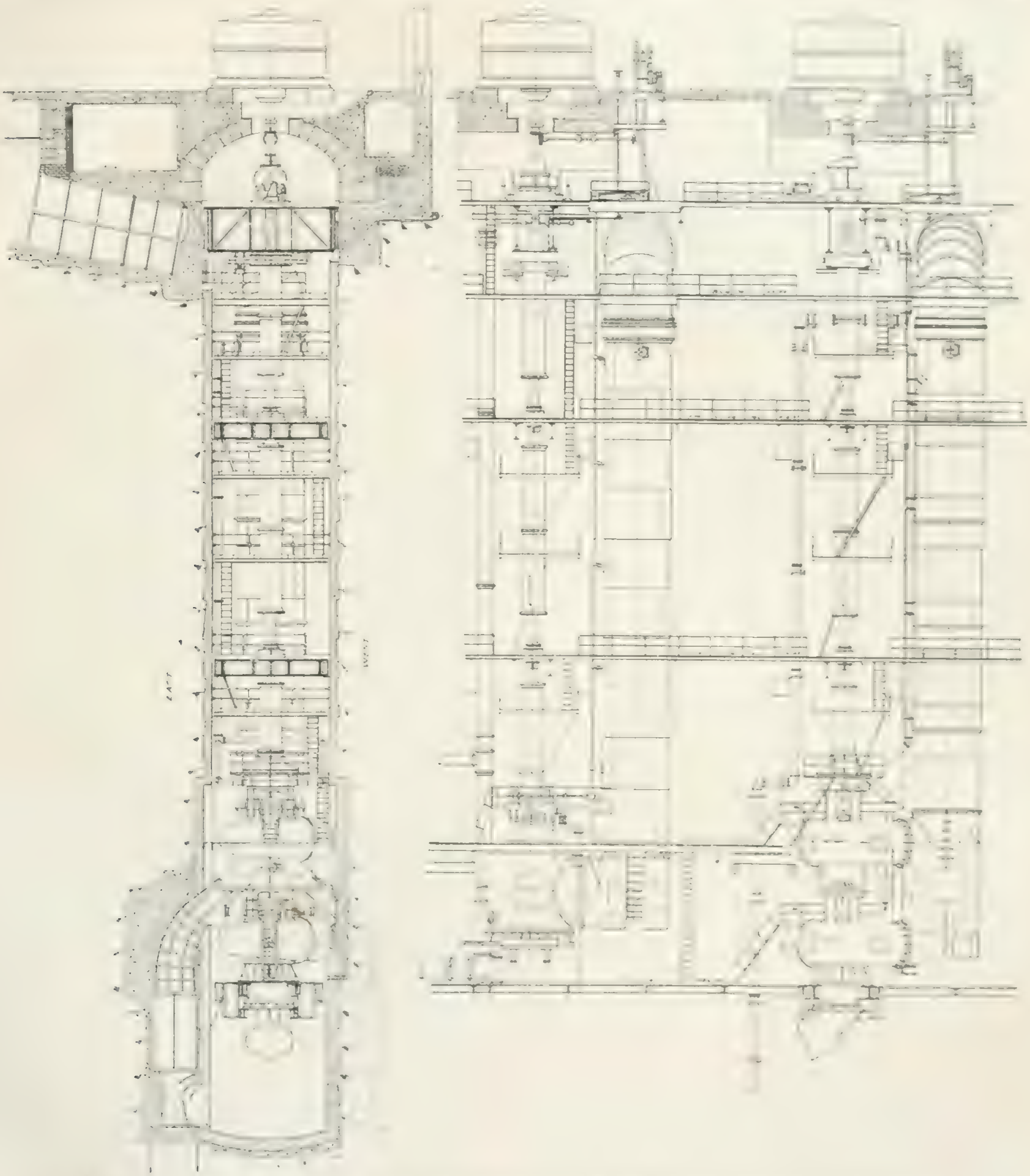


FIG. 2—ELEVATION OF THE 10,000 AND 12,500 HORSE-POWER [illegible]

study and design, as it was very important that any alteration in or addition to the original plans should not detract from the appearance of the building. In studying the architectural requirements it was found necessary to erect a structure much larger than that required to house the control room and it was decided to incorporate an office building in the projected addition. Fig. 1 is an outside view showing the architectural features finally evolved. In order that the offices adjacent to the control room should not constitute a fire hazard, no [illegible]

A ventilating system for the office and control room was provided consisting of an air washer, blower and exhauster. The windows are used only for letting in daylight as the provision for circulation of air is independent of them. For circulation in the summer time air is obtained from outside the building, but in winter a supply of warm air is drawn from the main power house just underneath the roof. So far as the writer is aware, this is the first use which has ever been

made of the waste heat from electric generators. Experience has shown that a comfortable temperature can be maintained in winter with this waste heat without assistance from any other source, except in the very coldest weather. Electric heaters are installed in a

FIG. 3—INTERIOR VIEW OF PLANT

chamber in the air supply pipe, which are turned on during the few days when additional heat is needed.

In the control room is located a double 35-panel switchboard arranged in the form of a semi-ellipse. A portion of this board is shown in Fig. 4. The desk of the electrician-in-charge is located in such a position that when seated at it he can face almost directly any of the switchboard panels. The feeder, generator and bus junction control panels are arranged in the order in which the corresponding switches are located in the power house.

There are two groups of oil switches on the power house floor mounted directly over a subway which runs the full length of the power house and contains the main bus-bars. Eight sets of bus-bars are provided with bus junction switches for connecting adjacent ends of the sections. In addition to this, cables with bus junction switches connect the bus-bars at the extreme north and south ends of the power house, thus forming a ring system. In emergency a generating unit from one end of the power house can be used to supply energy to a bus-bar at the other end of the power house. Great flexibility in combination of generators is thus obtained, which experience indicates is justified in order to secure the highest efficiency of the plant.

Each generator is provided with two non-automatic oil selector switches so that it may be connected to either or both of two sets of bus-bars. Each feeder is provided with three oil switches. Two of these are arranged as selector switches with respect to the bus-bars and the third or main switch is connected to the middle point of the others. The selector switches are connected to the bus-bars through disconnecting switches in the usual manner. The main feeder switch is shunted through a grid resistance of about 2.5 ohms and is the only one of the three which is automatic. Fig. 5 shows a diagram of the generator and feeder connections. In case of a short-circuit in a feeder the resistance switch opens, cutting into circuit the grid resistance which reduces the current to about 4 000 amperes. When the resistance switch has opened an electrical contact is made which closes the operating circuits on the selector switch or switches, which then make the final break in the circuit. Since the duty of rupturing currents resulting from short-circuits has been reduced to 4 000 amperes, no trouble whatever has been experienced with these switches. All oil switches, whether on generator or feeder circuits, are designed to carry continuously the current which may be expected when 12 000 horse-power is being delivered at 12 000 volts.

There are seven telephone stations on the power house floor and in the main subway directly connected to a telephone in the control room. In case the operator in the control room wishes to communicate with an attendant on the power house floor a whistle is blown and the attendant goes to the nearest telephone booth. A different number of blasts of the whistle is used to indicate the particular attendant desired. In case the attendant on the power house floor or subway desires to communicate with the operator in the control room, the call is made in the usual way with a magneto telephone. This method of communication has proven to be entirely adequate for every occasion. The cost of the equipment was but a small fraction of the estimated cost of some of the elaborate signaling systems proposed.

In order to provide against excessive damage from short-circuits all the generators are regularly excited from induction motor-driven exciter generators. The induction motor-generator exciter sets are each driven from the battery of generators which they excite. Experience has shown that with this arrangement of excitation but little damage results to the lines

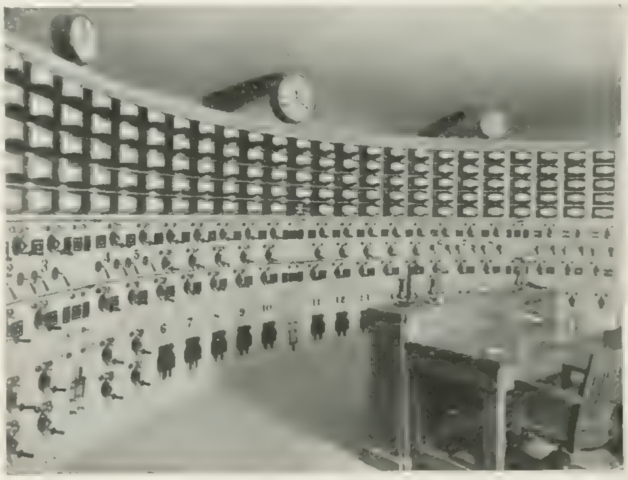


FIG. 4—PORTION OF SEMI-ELLIPTICAL, 35 PANEL MAIN CONTROL BOARD

or cables involved in short-circuits, as the induction motors quickly slow down under the reduced line voltage and this in turn reduces the direct-current exciter voltage. Turbine-driven exciters are provided so that current is readily obtained for starting in case the

entire plant should be shut down. Energy at 11 000 volts is also available from the American plant for starting the motor-generator exciter sets in case of a complete shut down. Still further a storage battery has been provided which has sufficient capacity to excite a generator long enough to start one of the motor-generator sets.

To provide a positive means of shutting off all energy in case of emergency, such as a breakdown in the armature of one of the main generators, an emergency switch equipment has been provided with connections so arranged that the operator in the control room, by closing a small switch, can instantly open the field circuits of all of the alternators connected in one group. This emergency switch arrangement has been used for a number of years in the plant of The Niagara Falls Power Company. In the Canadian plant, however, the emergency device has been so arranged, in connection with the control switches on the emergency switchboard, that when a generator is connected to a bus-bar the emergency switch connection is made at the same time. This grouping of the emergency field tripping devices to correspond with the grouping of the generators is entirely automatic and positive and requires no selective action on the part of the operators.

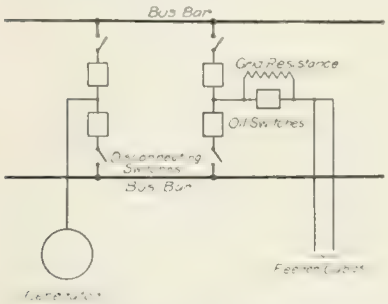


FIG. 5—DIAGRAM OF GENERATOR AND FEEDER CONNECTIONS

A 60 cell storage battery has been installed which is capable of delivering 1 000 amperes for five minutes, 400 amperes for twenty minutes, or 50 amperes for eight hours. This storage battery is provided with a switching device which divides the cells into two equal sections for charging. In case the voltage on the direct-current system falls below 100 the storage battery is automatically detached from the charging system and the two halves connected in series. This storage battery is connected to supply a few lights in the control room, power house, subways, and wheelpits, so that, in case the entire plant were shut down, sufficient light would be furnished for the attendants to find their way around the plant. It also supplies energy for operating the head gates and electrically-operated switches. The battery has sufficient capacity to close all of the head gates and operate all the switches simultaneously.

A graphic recording watt-meter has been provided for measuring the entire output of the plant. This meter is built with eleven actuating elements, one for each generator. Seven of these are already in service with four elements ready for additional units when installed. The actuating elements are constructed on the dynamometer principle and are entergized by series and shunt transformers connected to the leads from each generator. Consequently whenever a generator is delivering energy, no matter what the frequency or voltage or whether paralleled with other generators or not, the output is included in the registration on the graphic chart. The paper chart is 18 inches wide and the instrument is calibrated to record up to 100 000 kilowatts. The chart and recording mechanism are driven by a special direct-current motor operated from a storage battery. A complete graphic record of the output of the plant is thus obtained. This record furnishes a valuable check on reports of trouble as reported by operators. Frequently the story told by the graphic chart enables one to trace out the cause of trouble and the sequence of happenings which would be inexplicable from the reports received from other sources.

A safety device to prevent mistakes in operating disconnecting switches has been devised which may be of interest. The switches are mounted in brick cell compartments, each of which is closed in front with an asbestos door. The doors are arranged in groups of three and are provided with electric spring locks, the three locks of each group being in series. The doors can be unlocked only by special long break push switches located on the control panels of the main switchboard. The doors normally remain locked. When switching is to be done the electrician-in-charge issues the necessary instructions to his assistant and then pushes the button which controls the doors to the compartments containing the switches concerned. The doors on being unlocked swing partly open. If the compartment doors which the assistant finds open are not those indicated in his instructions, no switches are thrown by the assistant operator until the matter has been straightened out. Of course there is no absolute safeguard against mistakes in switching, but this arrangement makes it necessary for two men to make the same mistake, a thing highly improbable, before an error in switching can be made.

In the design of this plant the idea constantly kept in view was that of simplicity. In these times when the fertile minds of engineers have devised and built almost every conceivable instrument and device for power plant equipment, it is difficult to resist the temptation to incorporate them in the design and to install them. In a very large plant the operating features must be simplified as much as possible if continuous service is to be secured or even closely approximated In the case under consideration a large amount of energy used for power purposes is generated and delivered in bulk in large units. The distribution of this energy presents problems arising from magnitude rather than from multiplicity of details. The load is unusually constant and involves a minimum amount of switching so that one switchboard attendant can look after the entire plant. All of these conditions making for simplified treatment were taken advantage of to the fullest extent. The equipment has been reduced to its lowest terms and, I believe, in an unusual degree for an installation of this character, combines simplicity and flexibility.

Large Incandescent Lighting Units

A. R. DENNINGTON,

In Charge of Lamp Development,
Westinghouse Lamp Company

SINCE the advent of the incandescent lamp there have been continuous developments which have resulted in better efficiencies and better lamps of large as well as small wattage ratings to meet the commercial requirements of the times. With the reduction in the energy required per candle-power has come the tendency to use increasingly greater intensities of illumination. The larger sizes of lamps have always proved most efficient while the small sizes have met the requirements for lighting small rooms, individual desks, etc. During the period when the carbon lamp monopolized the incandescent lighting field, individual units absorbed usually from fifty to one hunhundred and fifty watts, practically all of which was dissipated as heat. Less than five percent of the energy

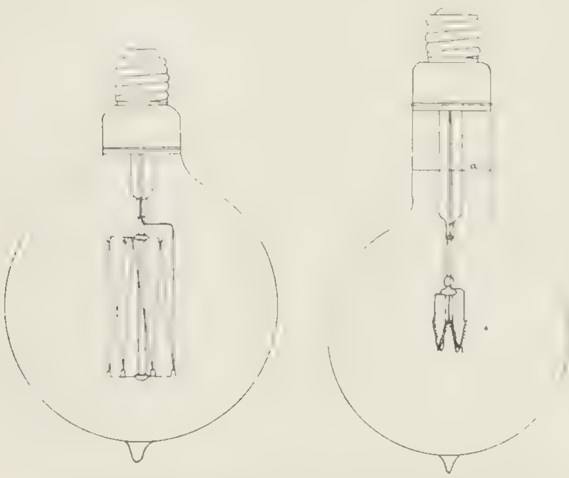


FIG. 1—RELATIVE SIZES OF A 500 WATT VACUUM LAMP (LEFT) AND A 1 000 WATT NITROGEN FILLED LAMP (RIGHT)

was radiated as light. In the development of the metal filament lamp it was found possible and commercially practicable to construct lamps having wattage ratings of 400 and 500 watts. A few lamps of even higher ratings were developed, but owing to ungainly size they were never of special commercial importance. Large bulbs were found to be essential for these lamps in order that a satisfactory life might be obtained without excessive blackening caused by the evaporation of the filament and the deposition of the metal particles on the inner surface of the bulb. With a large bulb the metallic deposit is thinner after a given number of hours burning than with a small bulb. The blackening was therefore the determining factor in the selection of the size of bulb for a lamp.

In the latest type of incandescent lamp the filament is not heated in a vacuum, but in an atmosphere of inert gas, such as nitrogen. Special care is exercised to provide a gas which is free from moisture or any element which can combine with the filament. The filament can be brought to a higher temperature in the atmosphere of gas than in a vacuum without excessive evaporation of the metal taking place, and hence under certain conditions it is possible to produce a highly efficient source of light. The introduction of gas into the bulb of a lamp is in some respects a disadvantage, as it tends to cool the filament by carrying the heat away on the convection currents which are set up. Owing to this effect small filaments, which have comparatively greater surface areas than large filaments, are cooled so effectively by the gas that a much greater expenditure of energy is necessary to maintain a given temperature than in a vacuum. A gas filled incandescent lamp of high efficiency therefore requires a large filament, the surface of which exposed effectively to the cooling currents of the gas is further reduced by coiling the wire on a mandrel slightly larger than its own diameter. In this way the total heat developed in the filament by the passage of the electric current is localized and raises the temperature to such a degree that an extremely brilliant light is obtained. Large filaments require large currents to heat them and hence the gas filled lamp is specially adapted for large units. Because of the reduction in the evaporation of the filament and also because of the fact that any metallic particles are carried up by the convection currents and deposited in the upper part of the bulb out of line of the useful light rays it is possible to use much smaller bulbs than for vacuum lamps of equal power input. The relative sizes of a 500 watt vacuum lamp and a 1 000 watt nitrogen filled lamp are shown in Fig. 1. The use of gas in the bulb permits the expenditure of double the energy of the vacuum lamp in a smaller bulb. However, the neck of the bulb of the gas filled lamp is extended so as to form a cooling chamber and also to allow the base and socket to be kept as far away from the filament as practicable.

The production of light by the expenditure of electric energy is a result of the development of heat in the material carrying the current. The greater the heat which can be developed in a filament of given dimensions the greater the temperature and conse-

quently the greater the light per unit of power [illegible] a small amount of power, probably less than five percent of the energy supplied to a vacuum lamp of large size or less than ten percent of the energy supplied to the most efficient type of gas filled lamp, is radiated as light, the remainder being dissipated as heat.

FIG. 2—DIAGRAM SHOWING DIRECTION OF CONVECTION CURRENTS OF GAS IN A GAS FILLED BULB

Heat is given off from the filament of a vacuum lamp in the following ways:—by conduction through the leading-in wires, anchors, glass arbor and stem to the base and the bulb; by radiation from the filament through the vacuum surrounding it to the bulb which is in turn cooled by the air currents. The transfer of heat from the filament to the whole surface of the bulb is fairly uniform and no part of the bulb gets excessively warm. If the lamp is burning in a pendant position, as is usually the case with large units, the base may be at a somewhat higher temperature than the lower part of the bulb because of the convection currents in the air surrounding the lamp and also because of the I^2R loss in the contacts between the base and socket.

The conditions resulting from the filling of the lamp bulb with nitrogen or other inert gas are in some respects widely different from those outlined for a vacuum lamp. The filament is more concentrated and the heat radiation is in straight lines from this point. Heat is also dissipated by conduction through the gas, leading-in wires and stem, these two effects being similar to the corresponding one in vacuum lamps. However, the conduction effect is greater in the latter case because of the gas acting as a conductor of heat. The most noticeable effect of the gas in transferring heat from the filament is due to the convection currents set up within the bulb. These convection currents, as indicated by the arrows in Fig. 2, rise vertically from the filament and this current of hot gas is cooled by contact with the bulb. As the gas is cooled it increases in density and flows down near the inner surface of the bulb to a region below the filament from which it again rises through the source of heat, thus completing a cycle. The heating effects of the convection currents are very noticeable near the filament. Any metal support which comes directly above a section of heated filament is raised to a much higher [illegible] out of a vertical plane through the filament. The efficiency of the lamp may also be made to vary widely by changing the position of the filament so as to afford a greater or less cooling by means of the convection currents. For example, in Fig. 3, where the coiled filament is in a horizontal position there will be produced a convection current which will bring cool gas to all parts of the coil and hence an excessive amount of energy is carried away in this manner. Since the horizontal position of the coil gives the greatest exposure to the convection currents the efficiency will be the least for a given current through the filament. With a coil placed in a vertical position, Fig. 4, the area exposed to the convection currents is a minimum and hence the best efficiency will be obtained. In this case the current of cool gas rises along the coil and carries the heat from turn to turn. The temperature of the gas current increases with the distance it rises along the coil and consequently the cooling effect is reduced. Long vertical coils will have comparatively less cooling than short ones from the gas and also from the leading in wires and consequently will operate at better efficiencies. As the current of gas rises above the filament it diffuses to some extent, but carries considerable heat to a comparatively small area at the top of the bulb. Pendant lamps allow the current of heated gas to strike inside the base and unless proper precautions are taken the base and socket may reach a temperature high enough to cause deterioration of the cement which holds the base to the lamp, melt the wax used in the socket to fill up the screw holes, melt the solder which connects the terminal wires of the lamp to the base and seriously increase the fire risk. For this reason proper precautions should be taken to assure thorough

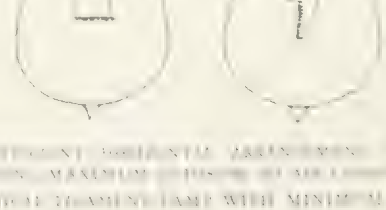


FIG. 3—[illegible] FILAMENT [illegible] MAXIMUM [illegible] FIG. 4—VERTICAL FILAMENT LAMP WITH MINIMUM [illegible] CONVECTION CURRENTS

ventilation of shades, reflectors and enclosing globes used with lamps of high wattage.

The neck of the bulb of a large lamp is sometimes obstructed by a mica disk *A*, Fig. 1, placed a distance of one or two inches from the base. The convection currents from the filament rise only to the disk, then cool and descend. In the space above

the disk local convection currents of low velocity are set up and help to transfer the heat from the disk to the upper portions of the neck of the bulb and to the base. There is a much higher temperature at the lower surface of the disk than above it and hence the base and socket are kept comparatively cool. This is the great advantage of the mica disk. The chief disadvantages are the following. Local blackening will occure lower in the bulb than if no disk is used because the convection currents are prevented from rising higher than the disk. Stresses are set up in the glass due to the unequal heating above and below the disk and these stresses may result in the bulb cracking off on a line around the disk as though heated by a hot wire and suddenly cooled. Breakage of the same kind occasionally occurs at the edge of the base if no disk or baffle is used. However, the use of a bulb with a long neck has eliminated this type of failure except where the lamp is used in a fixture which gives inadequate ventilation or insufficient protection from the weather.

It is necessary to dissipate a considerable amount of heat when a lamp of high wattage is used and in order to do this considerable free space is required above and around the lamp. Large lamps are therefore not suitable for use close to ceilings which are of a combustible nature. If it is necessary to place the lamp near the ceiling a ventilating flue of some kind should be installed so that the heated air may pass off without danger of causing undue rise in temperature. In short, ventilating space must be provided similar to that which would be required for a gas lamp dissipating an equal number of heat units per second. For example, a five cubic foot gas lamp will deliver by the combustion of the gas approximately 2 500 B. t. u. per hour or 0.695 B. t. u. per second, which is equivalent to 175 gram-calories per second. One gram-calorie per second is equivalent to 4.16 watts. Hence, 175 gram-calories are equivalent to 728 watts. This shows that the heating effect of a 750 watt incandescent lamp is about the equivalent of a five cubic foot gas burner.

Enclosing globes and shades which have not adequate ventilation are liable to cause failure either of the lamp or the shade. If the heated air cannot escape from the upper part of the globe or shade the adjacent parts of the fixture are called upon to radiate the heat. This results in the setting up of stresses in the glassware and ultimately in breakage of the globe, overheating of the socket, or failure of the lamp bulb. The temperature may be so high and maintained for a time long enough to cause the copper leading-in wires of the lamp to be oxidized so that they break. The danger from falling glass where lamps are improperly installed is serious and gives another reason for taking special precautions in selecting suitable fixtures.

Large lamps which are installed where they are exposed to the weather should be provided with hoods which protect the upper part of the bulb from moisture. The upper portion of the bulb is much hotter than the portion below the filament and the sudden local cooling caused by rain or snow on the heated glass may cause the bulb to crack. Special glass which may be heated and suddenly cooled without danger of breaking is used in some cases for lamps designed for operation in exposed positions. Owing to the difficulty of working this hard glass and inexperience in its manipulation the bulbs made from it are less perfect than those made from the soft lead glass ordinarily used. The imperfections are usually in the form of streaks or bubbles and have but little effect on the radiation of light from the filament.

As the filament in a gas filled lamp is wound in a small closely spaced spiral it takes up very little room in the bulb and consequently the light is radiated from practically a point source. The high intrinsic brilliancy of the filament makes it imperative that the lamp be placed well out of the ordinary field of vision or be enclosed in a diffusing globe or both. Not only is the direct radiation from the filament extremely uncomfortable and fatiguing to the eye but also it is injurious and may produce temporary or permanent defects of vision. The efficiency of the lamp is such that even with diffusing globes the lighting of a given area may be accomplished very economically. Reflectors and globes should be designed and arranged so as to redirect and diffuse the light with a minimum of loss and absorption. The color of the light is much whiter than that obtained from the most efficient types of vacuum lamps.

The high candle-powers obtainable, the absolute steadiness of the light and the small amount of attention required by a gas filled incandescent lamp makes it a strong competitor of the most efficient types of arc lamps. In many installations the nitrogen filled lamp will require no attention whatever during its long life of about one thousand hours and in other cases the only attention is the cleaning of the bulb or enclosing globe in order to get the best effect, thus the power cost and the prorated cost of the lamp are the only costs to be considered. Variations in voltage have about the same effect on the gas filled lamp as on the older form of lamp with tungsten filament. Changes in the frequency of alternating-current systems will have less effect on the gas filled lamp than on a corresponding vacuum lamp because of the temperature equalizing effect of the gas. Heat is stored in the gas during the peak of the current wave and and given up later when the current value is passing through zero.

Voltage Regulation of the West Penn System

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Assistant General Manager,
West Penn Traction and Water Power Company

THE subject of voltage regulation has been given entirely too little thought and attention by central station men in the past. The time is now at hand when voltage regulation must be improved as the consumer is not only demanding it, but the various public service commissions specify and will very shortly compel better regulation.

Perhaps no other phase of the service more easily tends to create dissatisfaction among light and power users than the existance of wide fluctuations in voltage. Not only is this true, but the highest efficiency cannot be obtained from the system while such a condition exists. The amount of compensation required on a distribution system to maintain constant potential to the individual consumer depends upon the amount and character of the load and the length and characteristics of the feeders. Since the peak load occurs at different times on different feeders it is evident that good regulation of the entire system can be maintained only by the regulation of each feeder independently.

Realizing the importance of individual feeder regulation, in the early days of the West Penn Company, about 1900, each lighting feeder was equipped with a hand-operated, switch type regulator known as the Stillwell regulator. This regulator consisted of a transformer—the primary of which was connected across and the secondary in series with the feeder, the secondary being provided with taps so arranged and connected to the switch that various numbers of turns of the secondary could be cut in and out of the circuit, with a further arrangement whereby the secondary could be made either to boost or buck the feeder by reversing it or by reversal of the primary.

This type of regulator answered very well when the West Penn Company was small, but when the system began to extend its feeders, supplying other territory and all kinds of service, the matter of regulation became a very important one and, being progressive, we started to investigate automatic regulators.

At that time there were no fully developed automatic regulators on the market so we designed several which we manufactured and tried out, besides carrying on experiments and testing regulators built by the large manufacturers. This investigation and test period lasted some six years during which time all types of regulators were investigated, among which were the various switch types, automatically controlled both by solenoids and motors, having both ratchet and worm gear, the switching of some being done in the main circuit of the feeder, the same as in the old Stillwell regulators, others by switching the primary current of the regulating transformers, and still others by switching the primary of an exciting auto-transformer which excited the primary of the regulating transformer. This last method was tried with the idea of eliminating some of the many troubles experienced in connection with switching the heavy currents, and proved to be the most successful switch-type regulator we investigated, being particularly flexible in that the exciting transformer was quite small, and yet could be applied to a number of different sizes of regulating transformers.

Other types consisted of floating series coils which were brought within the influence of the boosting or bucking field, the float coils being controlled both electrically and pneumatically through the medium of voltage relays; other types had a flexible cable secondary which was passed from the influence of either the boosting or bucking field to the other by coiling or uncoiling on reels which were located one in the boosting and the other in the bucking field; and still other types consisted of transformers having variable magnetic fields obtained by strengthening or weakening the magnetic circuit through the opening or closing of an air-gap in the laminated iron structure. All of these regulators proved undesirable on account of the various complications and difficulties which developed during the tests.

At last we tested and decided in favor of the induction type regulator on account of its simplicity and reliability, giving due consideration to the fact that the consumer is the person to be pleased and that the consumer cares naught for the efficiency of the producer's apparatus, but is deeply interested in the quality of the service rendered; hence, it has been necessary in our experience to adopt apparatus which would be the most satisfactory to the consumer.

All of the induction type feeder regulators at present in service were furnished by the Westinghouse Electric & Mfg. Company and are of the latest type and design, consisting of a series coil revolvable in a magnetic field in such a manner that the field may be caused to cut the coil at different angles, which has the effect of inducing in the coil a current which either boosts or bucks the feeder in which the coil is connected, depending upon the position of t… coil in the magnetic field. The position of the coil is controlled by a small motor th… medium of a worm gear, the motor i… controlled by a primary relay connect

feeder. Each regulator is equipped with automatic accessories consisting of a primary and secondary relay, a line drop compensator and voltage and current transformers. The line connections to the regulators, as well as the leads to the auxiliary apparatus and the operating motor, are made by means ing short-circuited and then the switch opened, which will disconnect the regulator from the circuit entirely. This makes it possible to cut the regulator in or out without causing an interruption of the consumer's service. The auxiliaries and operating motor are controlled by separate

FIG. 1—MAP OF THE TERRITORY SERVED BY THE WEST PENN TRACTION & WATER POWER COMPANY

of switches and interleaved or knuckle joint contactors so that the regulator and accessories can be ...nd quickly disconnected.

...main switch through which each regula...ted is so arranged that the regulator ... the neutral position, the series wind- switches, making it possible to control the regulator in any manner desired without disconnecting a single wire. In addition to this, all the auxiliary parts for the regulator are mounted on a small panel attached to the top of the regulator and located just back of the operating mechanism. This makes the

regulator with all its accessories a complete unit.

A single-phase automatic induction regulator is placed in each phase of all the feeders, which are two-phase in the majority of cases. Where the voltage is transmitted at 6600 volts, regulators are placed in the main sub-station on the 6600 volt side of the step-down transformers. There are a few exceptions to this, however, where the voltage is stepped up from 2200 volts to 6600 volts for distribution, in which cases the regulators are placed on the 2200 volt side of the step-up transformers.

The necessity for regulating the various two and three phase circuits at both 2 200 and 6 600 volts would lead one to believe that the feeder regulators would be of a great variety. On the other hand, we adopted an equipment consisting of but two main frames with but one type of auxiliaries, the frames being rated at 16.5 and 22 kw at 6 600 and 2 200 volts respectively in the smaller sizes, and 33 and 44 kw in the larger sizes, all being single phase; hence, the necessity of installing a regulator on each phase to be regulated. However, there is a further advantage in such an arrangement in that we have not only been able to limit ourselves to the minimum number of kinds of regulators but also have been able to give very much better lighting service from our various feeders, by being able to control more accurately the phases on which the lighting service is connected.

In order to give a better idea of the magnitude of the system and to indicate more fully some of the difficulties which had to be overcome in the matter of regulating our system, a map, Fig. 1, is given showing the territory, about 2 500 square miles, in which the West Penn System operates and the numerous towns supplied with light and power, together with the tranmission system and the location of power and substations. The West Penn System includes 15 power stations, 32 substations, 434 miles of 25 000 volt three-phase transmission circuits, 250 miles of 6 600 volt feeders and 4 200 miles of 2 200 volt distribution supplying 82 166 kilowatts in motors and electric lights. This service is rendered single, two and three phase, 60 and 133 cycle, at potentials of 50, 110, 220, 440, 1 100, 2 200, 6 600, 11 000 and 25 000 volts alternating current, and at 250, 500 and 750 volts direct cur rent. This multiplicity of service is due to the fact that the West Penn System consists largely of the development of small independent properties which have been purchased, and each individual property had some pet system of its own in use to such an extent that it is now impossible to rehabiliate every-extent that it is now impossible to rehabilitate every-every substation single, two and three-phase service is supplied at potentials of both 2 200 and 6 600 volts, while many of them have a greater combination including direct-current service and perhaps high frequency. This large territory and multiplicity of service requirements necessitated some 200 automatic regulators.

The difficulties in regulating a system such as described—especially considering the fact that it is spread out over such a large territory—are manifold when compared with those of a system supplying a congested territory. Ordinarily, the regulation at or near a power station is fairly good and the poor regulation is experienced only on the ends of the longer feeders but, in cases where a system covers a very large territory and feeders are particularly long, as in our case, the best that can be done is to regulate the transmission system for the best average conditions obtainable at the center of the system. This is accomplished on our system by regulating the generators at the power stations by means of Tirrill regulators adjusted to compensate for the step-up transformers and line losses to the center of the system, and at the sub-station by motor-generator sets of the synchronous type especially designed, having very great condensing capacity, all sizes above 100 kw being equipped with Tirrill regulators adjusted to help maintain the voltage constant at the sub-station or to improve the power-factor as the conditions require. Consequently, in order to compensate for the line loss of the transmission system the potential at or near the power station will vary approximately as it does at the extreme ends of the system, except that near the power station the variation is above normal, while at the extreme ends it is below normal and is at or near normal at about the center of the system.

The regulation of the feeder, which, in some cases, is more than ten miles long and furnishes all classes of service, is quite a problem, in view of the fact that the producer has no control of the manner in which the consumer operates his apparatus or throws his load on or off. Hence, the compensation for maintaining the potential constant at the center of the territory supplied by any feeder might be all up-set by an extremely heavy load thrown on the feeder near the station in which event the regulator would automatically raise the potential to compensate for the line loss for an average condition and on account of the load being close to the station, the potential would be raised unnecessarily high at the center of the territory on account of the line losses existing only in a very short section of the feeder, while the compensation can only be ajusted to take care of an average condition. However, if the conditions had been reversed and the heavy load had been thrown on at the extreme end of the feeder, a lower potential would result at the center as well as at the extreme end of the feeder. Due to this condition, even with automatic regulators on each feeder, it is impossible to maintain constant potential at any point, but this variation in potential can—with automatic regulators—be held within the requirements of any reasonable service.

There is, at the present time, an automatic regulator designed for pole line service which can be installed at various points along a long feeder to more nearly equalize the potential of the circuit, but generally this would not be practicable on account of the excessive first cost of such regulators and on account of the attention and maintenance necessary to keep them in good operating condition, and is an unnecessary refinement which the majority of consumers could not afford. However, there is no question but that there are cases where such a regulator could be used to advantage.

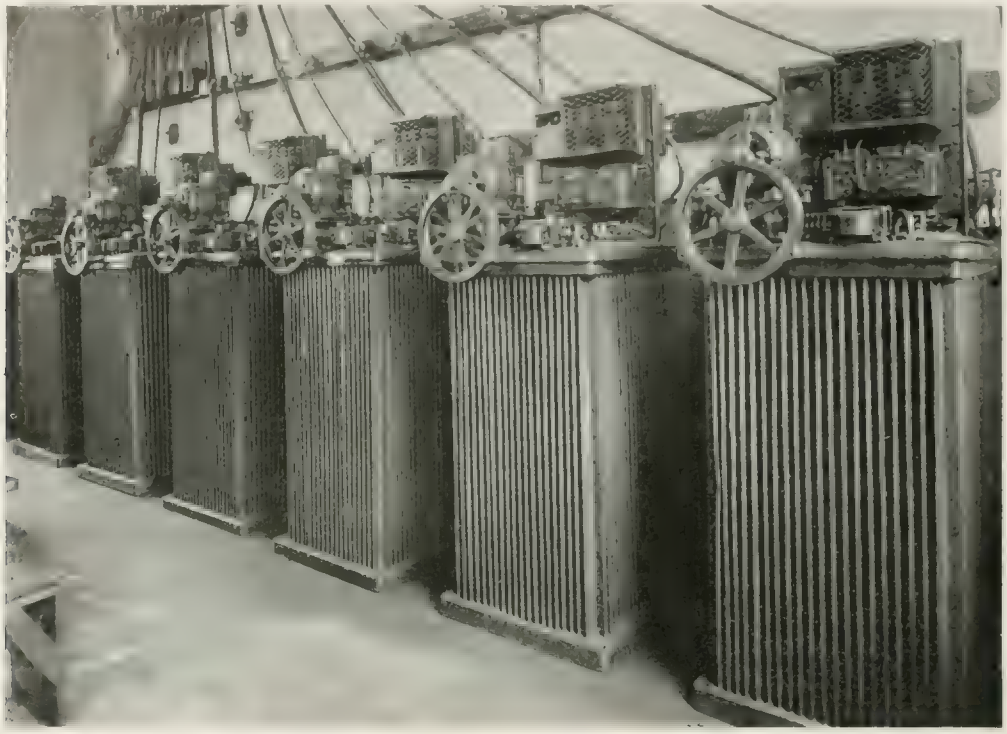


FIG. 2—VOLTAGE REGULATOR INSTALLATION AT MANOR SUB-STATION

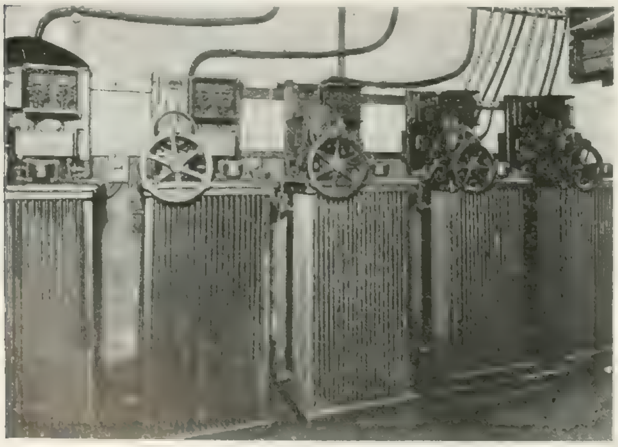


FIG. 3—UNIONTOWN INSTALLATION, SHOWING WIRING ARRANGEMENTS FOR TWO VOLTAGES

One particular advantage of the automatic regulator is that feeders may be more heavily loaded and yet perfectly satisfactory service rendered, thereby making a great saving in the cost of reinforcing or primarily constructing extra heavy feeders, for without automatic feeder regulation it is necessary to have a wire of such size as to carry its maximum load with a very slight drop, in order to give satisfactory service. We have had many cases where the installation of automatic regulators has saved us the cost of reinforçing the lines while the cost of the regulator was only a very small fraction of the reinforcement. At the same time the average losses of the line were not excessive and would not justify a reinforcement when considered on the basis of all day loss, but under peak conditions the losses were so excessive that the service was limited and the earning capacity of the feeder curtailed.

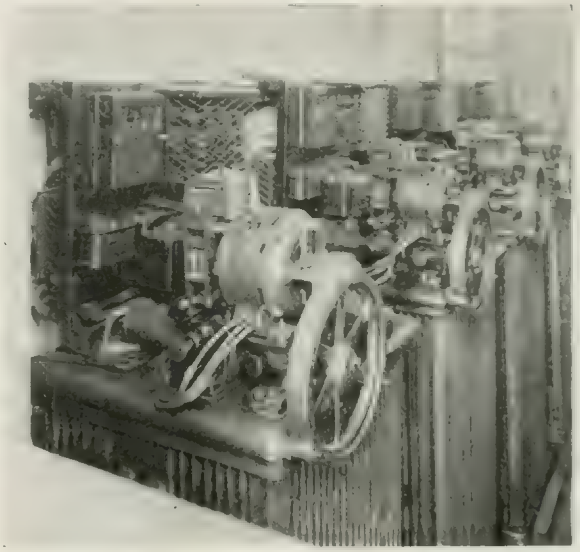


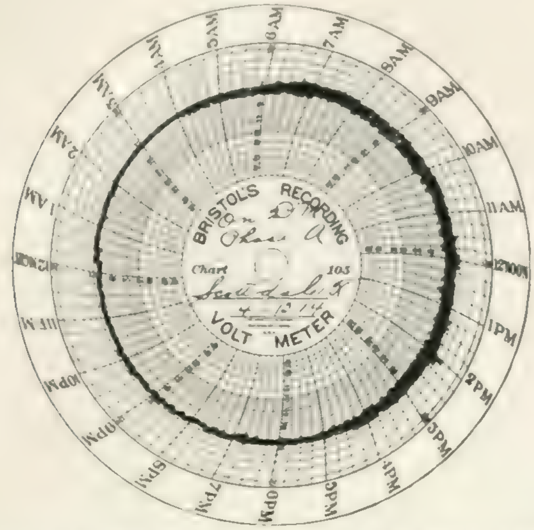
FIG. 4—IRON BRIDGE INSTALLATION OF FOUR 33 K.V.A., 6 600 VOLT REGULATORS

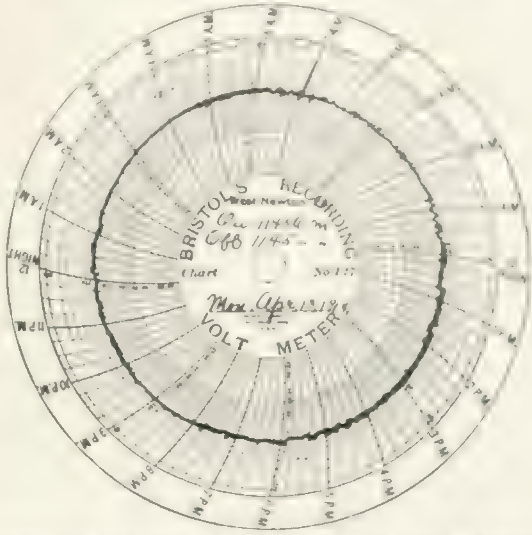
A typical installation is shown in Fig. 2, which was taken at the Manor sub-station, consisting of six 44 k.v.a., 2 200 volt regulators. It can be seen

that there are apparently four wires leading to each group. Three of these in a group are the feeder lines and the fourth is a flexible conduit containing the four wires from the voltage and current transformers.

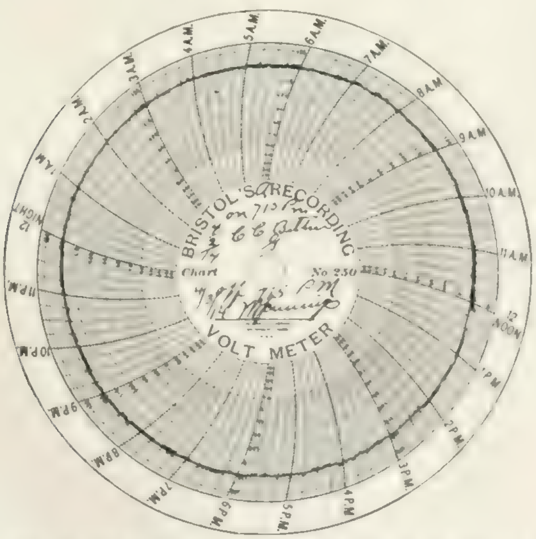
Two methods of lead arrangement at Uniontown are shown in Fig. 3. In this sub-station there are installed four 44 k.v.a., 2 200 volt regulators and two 16.5 k.v.a., 6 600 volt regulators. Owing to the arrangement of the transformers in this room, it was impossible to get the sixth regulator in the illustration. The regulators on the left are connected to 2 200 volt circuits while the two on the extreme right are for 6 600 volts. Fig. 4 shows four 33 k.v.a., 6 600 volt regulators installed in the Iron Bridge sub-station, two of which are connected in the Scottdale feeder and two in the Mount Pleasant feeder.

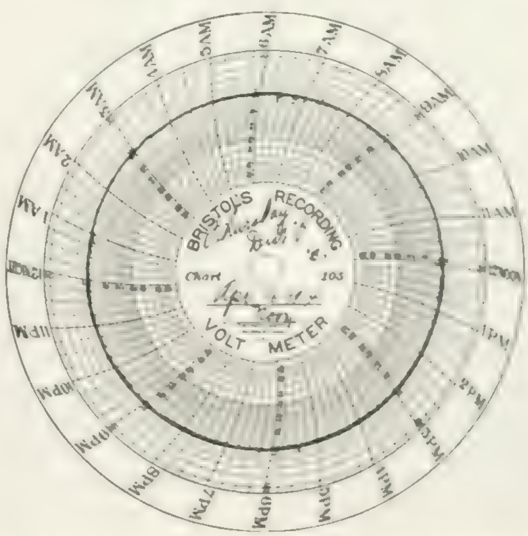
The results being obtained are very gratifying and are probably best shown by means of graphic voltmeter charts. The charts shown in Figs. 5 to 8 inclusive were all taken at about the center of distribution of their respective feeders and are evidence of the good results that are being obtained. The chart taken at Scottdale is much better than may be imagined at first glance, as the pen is about two volts wide, causing the fluctuation to appear more pronounced. This chart was taken on one phase of a 6 600 volt, two-phase feeder which is fed from and regulated at the Iron Bridge sub-station about three miles away. This feeder supplies many manufacturing plants, among them the United States Cast Iron Pipe & Foundry Company's plant, the largest cast iron pipe mill in the world, and the power load is very heavy in comparison with the lighting load. Another example of a heavily loaded power feeder is shown by the chart taken at West Newton. While this chart appears somewhat ragged, the average value of the voltage fluctuation does not exceed two volts plus or minus, which is less than two percent variation. The chart taken at Charleroi gives a good idea of the voltage service rendered lighting customers. The feeder on which this chart was taken supplied only a small amount of current for power purposes, the larger part being utilized for lighting.





FIGS. 5 AND 6—VOLTAGE CHARTS TAKEN AT THE CENTERS OF DISTRIBUTION OF FEEDERS AT SCOTTDALE AND WEST NEWTON





FIGS. 7 AND 8—CHARTS SIMILAR TO THOSE OF FIGS. 5 AND 6, TAKEN AT CONNELLSVILLE (LEFT) AND CHARLEROI (RIGHT)

As can be seen, the voltage remained practically constant for 24 hours with hardly a variation. At Connellsville, the feeder on which the chart was taken has a small power load consisting mostly of individual applications which constitutes perhaps half the total load. While this chart is not as good as that taken at Charleroi, it is nevertheless exceptional, since the voltage variation is only about two volts. While the voltage at the main station, which is located at Connellsville, will be varied considerably to compensate for loss of the transmission line, the voltage chart at the power station very closely resembles the wattmeter chart on a smaller scale.

An interesting fact in connection with these charts is that the results are obtained by so-called slow speed regulators, the time required for complete travel of the rotor from position of maximum buck to maximum boost being about eighteen seconds. This statement, however, is somewhat misleading. The desirable characteristics of an automatic feeder regulator is its ability to take care of the small fluctuations quickly and the time which elapses between the closing of the primary relay contacts and the operating motor reaching its full speed, is the determining factor. Of course, the reverse of this operation, namely, the opening of the contacts and the stopping of the motor must also be taken into consideration. The features of the automatic equipment which reduce this time element to a small fraction of a second and make close regulation possible are more essential than the ability of the regulator to make its extreme travel in a short period.

During our various experiments in the early days we were aiming at a three to five second regulator, i. e., a regulator that would go from full buck to full boost in from three to five seconds, but our practice has shown us that such a regulator would operate unnecessarily and would hunt, for in order to withstand the strain set up in such rapid operation it was necessary to make the apparatus very rugged, thus increasing the weight to the extent that the regulator would frequently overrun, and instead of obtaining better regulation, poorer regulation was invariably the result of using high speeds. Furthermore, the maintenance of the apparatus was increased beyond reason.

In summing up, the writer wishes to state that good regulation and the apparatus necessary do not form the bug-bear that many think. In the first place the apparatus is now developed to a wonderful state of perfection and after being properly installed requires practically no attention beyond that given the ordinary sub-station apparatus; and in the second place, the installation of suitable automatic apparatus makes it possible to render more and better service from the same feeders, and better regulation is one of the greatest factors in the sale of electrical energy. Therefore, better regulation resolves itself into a factor of greater earning capacity of a property.

Watthour Demand Meters

THEIR APPLICATION TO THE DEMAND SYSTEM OF RATES

C. A. Boddie

A CENTRAL station must always be ready to serve a customer and since, in the present state of the art, we have no satisfactory means of storing immense quantities of energy, a central station must generate the energy required on demand. For this reason an analysis of the cost of electrical energy is a much more complicated problem than that of the costs of commodities which may be produced at a constant rate and stored until required. Cloth, shoes, artificial gas, etc., may be produced at a uniform rate and sold at a fixed price per unit quantity. Similar rates have been used for electricity but have been found to lead to unfair discrimination among different classes of customers. Although the whole subject is still a matter of much dispute it is generally admitted that an equitable system of rates for electric service must recognize the customer's peak load. It has not, however, been easy to determine a satisfactory rate because of the difficulty of measuring the peaks accurately.

ELEMENTS IN THE COST OF ELECTRICAL ENERGY

An analysis of the cost of generating and distributing electrical energy shows that the total is made up of three leading items:—

1—Customer charge, including maintenance of meter, meter reading and billing. The total cost to the central station corresponding to this charge is proportional to the total number of customers, regardless of the size of the individual installations.

2—Fixed charges, which include interest, depreciation, taxes, insurance, transformer core losses and certain stand-by charges necessary to keep the system under voltage. The total cost of this charge to the central station is in proportion to the maximum demand of the consumer and is independent of the amount of current used.

3—Variable charges approximately proportional to the quantity of energy supplied, including cost of fuel, water and a part of the power house labor charges. The cost of this charge to the central station is in proportion to the amount of power used by the consumer.

It is obvious that a system of rates based on any one of the above items is apt to be inequitable to either the supplying company, the consumer or both. Consumers having particular individual requirements may be favored more than those having different requirements. In other words, the cost of supplying the service is not equitably proportioned

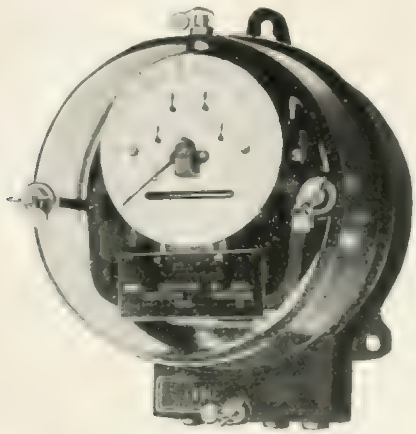


FIG. 1—GENERAL APPEARANCE OF WESTINGHOUSE MAXIMUM DEMAND METER

among the consumers. Charges should be proportional to cost, or as nearly so as commercial conditions will permit, otherwise the amount of profit derived from each customer is not the proper percentage of the reasonable value of the property employed in supplying the needs of the particular customer.

A few examples will serve to show the application and limitation of the various systems of rates:—

Suppose a station is to be designed to supply a single consumer whose needs and the character of whose load follow a regular cycle day after day. The size of such a station would be so chosen that it would carry the maximum load imposed on it, due provision being made for reserve equipment if continuous service be imperative. Costs in so simple a case as this could be accurately estimated and rates readily determined proportional to cost. A simple flat rate, such as $25 per horse-power year, could be used.

Suppose the maximum load to remain as before while the hours of use per day vary. It is evident, in the case of a steam-driven power plant, that the amount of fuel consumed will vary with the quantity of energy consumed. A simple flat rate is therefore not applicable as the charge should vary with the energy consumed. A straight kilowatt-hour charge could be applied in this case. It would, however, yield too small a return if the energy consumed were small and too large a return if the energy were large, since the total costs as pointed out above do not vary directly with the quantity of energy supplied. If the consumption fluctuated between moderately narrow limits the approximation would be satisfactory for practical purposes. In the case of a water power plant the quantity of energy bears little relation to the [illegible]. Hence a simple [illegible] rate is not applicable to water power systems.

[illegible]

The proper method to use would be to make a fixed charge proportional to the fixed costs plus a kilowatt-hour charge proportional to the variable costs. The monthly bill would then consist of two items as follows:—

1—Fixed charge per [illegible]

2—Kilowatt-hour [illegible] kilowatt-hour.

Suppose now that the load, both peak and quantity of energy, vary from month to month. It is evident that the yearly fixed charges must be the same since the investment cannot be varied to suit the load. The above method could be applied as the simplest and most logical but the following could be used, as it gives the same result:—

1—Fixed charge per [illegible]

2—Kilowatt-hour charge.

This method, although somewhat more complicated, has the advantage of varying the charges to suit the service, the consumer paying the same yearly fixed charges but in monthly installments proportional to his monthly peak. If the station is to supply a number of customers it is evident that unless all the loads rise and fall in synchronism there will be a certain amount of over-lapping, so that the station will not be required to carry the

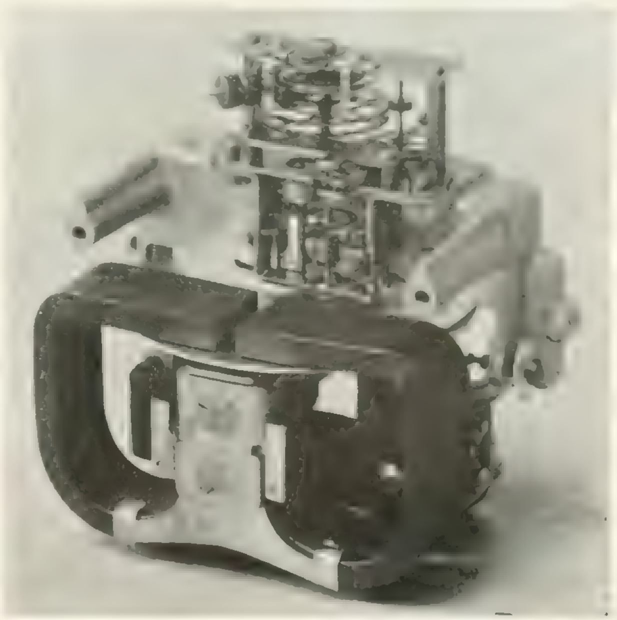


FIG. 2—FRONT VIEW OF METER INTERIOR
Dial mechanism and pointer removed

sum of the individual peaks. Hence the fixed charges to be carried by each customer will be reduced by an amount depending on the diversity factor.

The above method of computing the fixed charges bases the charge on the maximum yearly peak. If, however, we use the average of all the monthly maximums as the measure of the fixed

charges we will arrive at a rate which is approximately as much too low as that derived by neglecting the diversity factor is too high. Hence the diversity factor, which is an uncertain variable, may be neglected and the resulting formula for annual fixed charges is rational, practical and accurate within commercial limits as follows:—

Annual fixed charges = fixed charges per kilowatt per year × average yearly peak,

but

Average yearly peak = sum of 12 monthly peaks ÷ 12.

Hence the yearly fixed charges are:—

$$\frac{\text{Fixed charges per kilowatt per year}}{12} \times \text{sum of monthly peaks.}$$

Or the monthly fixed charge is

$$\frac{\text{Fixed charges per kilowatt per year}}{12} \times \text{monthly peak.}$$

To determine a customer's monthly share of the fixed charges it is only necessary to know his monthly peak or maximum demand. Hence the need of an instrument to measure maximum demand. Owing to the frequently irregular character of a peak load there is considerable difficulty in determining just what mathematical function of the peak can be used as a measure of peaks which will also bear a direct and simple ratio to fixed charges. A customer's peak or maximum demand is a quantity which should be suitable for substitution in the last formula above for the purpose of estimating his fixed charges.

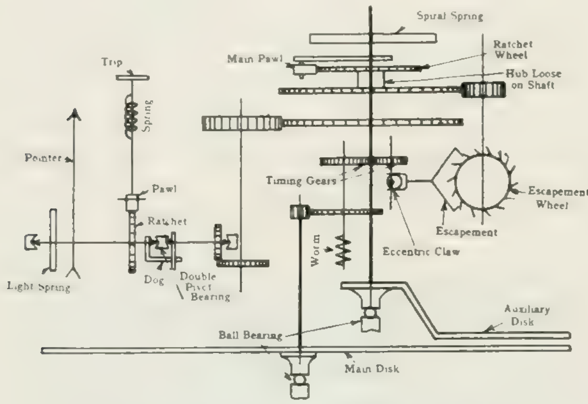


FIG. 3—SCHEMATIC DIAGRAM OF METER WITHOUT DIAL MECHANISM

The dial mechanism is geared to the worm near the main shaft.

MAXIMUM DEMAND

Maximum demand may be defined as:—*The maximum instantaneous rate in kilowatts in which energy is supplied.*

It is evident that in commercial service, rates based on this definition cannot bear any simple relation to actual costs even approximately. The definition is therefore undesirable and instruments giving this indication should not be used as a basis for rates. It is evident that inasmuch as electrical equipment is not affected by momentary loads, owing to its heat capacity, some element of time should enter the definition.

Maximum demand may therefore be defined as: —*The root mean square value of the load taken between two ordinates of time so placed that it will be a maximum.*

This definition introduces the element of time and makes the value proportional to the heating which is also proportional to the capacity of the equipment necessary for the service.

Maximum demand may again be defined as:—*The constant load in kilowatts which, if continued for a length of time equal to the time interval, will give the same integrated value in kilowatt-hours as the actual load integrated during the time interval, the interval being so chosen that the integral is a maximum.*

This definition contains all the elements usually involved in the so-called maximum integrated peak. While the definition itself is somewhat cumbersome, the idea expressed is simple. We have as yet no means of accurately measuring the maximum integrated peak. Demand meters are all devices whose indications depend on the peak and its duration. A time lag is introduced to make them commercially practicable. The devices offered so far have widely different characteristics yet, when properly considered, their indications can be used as a basis for rates. In view of the state of the art, the following is suggested as the only practicable basis for a definition:—

Maximum demand shall be defined to be the indication of an instrument so calibrated that when any constant load in kilowatts is passed through the instrument, it shall indicate the load in a predetermined time.

This definition includes all that can safely be put into a definition at this time. It is specific as regards loads and time, and affords a satisfactory basis for accuracy guarantees. For instance, we can require an instrument to be within two percent of an indicated steady load and say two percent on time, but no instrument has yet been devised which can be guaranteed to be within two percent of the maximum integrated peak. Recognition of the above factors entering into charges for electrical energy gives rise to a demand for instruments whose indication will serve as a means of determining the fixed charges to be carried by each consumer. A number of instruments have been developed for measuring the customer's peak load or maximum demand, the most notable of which have been built under the patents of Wright, Merz and Turner. These instruments are all very ingenious and have been used to a limited extent on service for which they were adapted, but they all contained elements which prevented their general adoption, such as high initial and maintenance cost, hand wound clocks, constant running, contact-making motors, delicate or unreliable mechanism, complication in wiring and installation, inaccessible mechanical con-

struction or difficult methods of calibration. As a result there has been a much felt need for an instrument suitable for measuring maximum demand under conditions imposed by modern central station service. The most important of these requirements

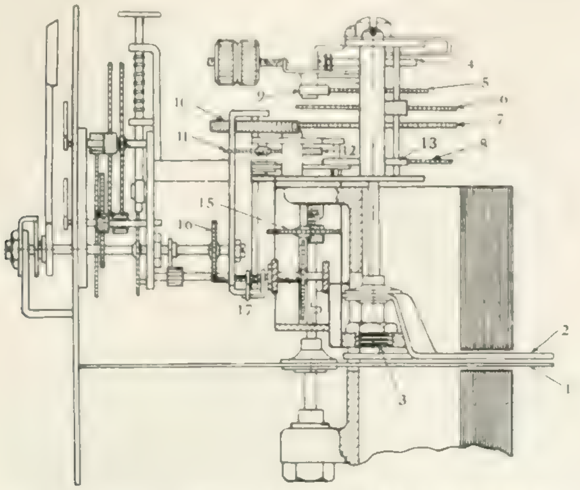


FIG. 4—VERTICAL SECTION THROUGH THE METER ELEMENT

is reliability. A meter to be used generally must be cheap, as the small revenue derived from the majority of installations will not permit the use of an expensive instrument. Experience with the watt-hour meter which has been developed to a high state of perfection, has imposed further requirements on the demand meter; it must be rugged, simple, compact, require very little attention or upkeep and must be capable of easy adjustment and calibration.

THE WATT-HOUR DEMAND METER

The instrument here described has been designed to meet these requirements. It is a single instrument that records both kilowatt-hours consumed and the maximum demand in kilowatts. It is installed as an ordinary watt-hour meter, and requires no additional apparatus or wiring. The meter has a definite time constant, yet contains no clock, contacts or delicate mechanism likely to give trouble in service, thus reducing maintenance costs to a minimum.

The general appearance of the single phase meter is much the same as a standard watt-hour meter. It is entirely contained in a case only seven inches in diameter. The maximum demand is indicated directly in kilowatts by a pointer sweeping over a four inch dial, the integrated load being registered on the usual four dial counter. The demand pointer is reset manually by pressing a button on top of the meter cover, thus making it unnecessary to open the meter. The button is sealed after each operation.

Construction—As shown in Fig. 4, the instrument consists of a watt-hour meter, including a standard electromagnet, permanent magnet and aluminum disc, geared to a standard counter. A second or auxiliary disc *2* is suported on a jewel and ball bearing [illegible] air gap of the electromagnet without interfering with the main disc. The series and shunt fluxes pass through both sides, inducing eddy currents which react on these fields in the usual manner, producing a torque in each, proportional to the load. The two discs are entirely independent, the auxiliary disc being so shaped that it does not interfere with the accuracy of the main disc, which rotates at a speed always proportional to the load. The auxiliary shaft carries a spiral spring *4* at its upper end, the tension of which opposes the deflection of the disc. The gear *7* fixed to the auxiliary shaft meshes with the gear *10* on the counter, thus transmitting the motion of the auxiliary disc through a dog drive to the demand pointer. A fine tooth rachet and pawl on the pointer shaft retains the pointer in its position of maximum deflection. Hence, if no other mechanism were introduced, the auxiliary disc would instantly deflect the pointer through an arc proportional to the load.

The auxiliary is, however, geared to an escapement wheel *8* which engages with a claw *13*. A forked lever fixed to the claw is caused to oscillate by an eccentric *14* geared to the main disc by gears 11, 12 and 15.

Principle of Operation—The action of the instrument is as follows:—The instant power flows through the instrument the main disc rotates at a speed proportional to the load, driving the watt-hour gear train and oscillating the escapement claw. The auxiliary disc tends to deflect instantly to indicate the load, but is prevented by the escapement claw engaging its wheel. As the claw oscillates,

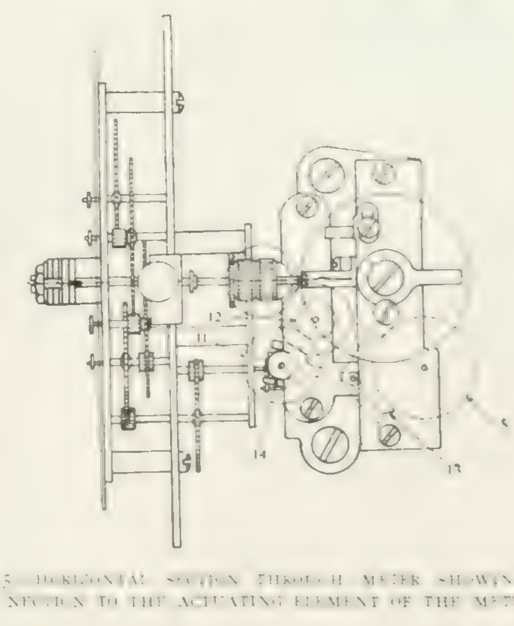


FIG. 5—HORIZONTAL SECTION THROUGH METER SHOWING CONNECTION TO THE ACTUATING ELEMENT OF THE METER

the teeth of the escapement wheel are allowed to pass one by one until the tension on the spring *4* balances the torque developed in the disc. The system is then in equilibrium, the demand pointer indicating the load, and although the main disc continues

to rotate so long as the load is maintained, no further deflection takes place, since the escapement claw oscillates freely between the teeth of the escapement wheel.

The mechanism is very similar to the ordinary

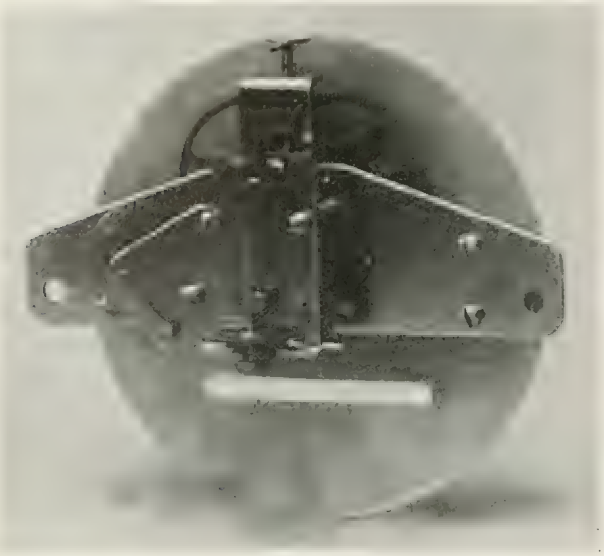


FIG. 6—REAR VIEW OF INDICATING MECHANISM

clock; the auxiliary disc furnishing the power for driving the escapement like a main spring, while the rate of movement is controlled by the motion of the main disc which performs the function of a balance wheel. The escapement wheel and claw have radial teeth to prevent an interchange of energy between the two discs. It is to be observed that the office of the main disc is simply to regulate the deflection of the auxiliary disc and it supplies no power whatever, except the negligible amount required to oscillate the escapement claw.

The escapement wheel is not driven directly from the auxiliary shaft by gear *6* but is driven by a ratchet wheel *5* mounted on a sleeve which is loose on the auxiliary shaft to which the gear *6* is attached. This ratchet wheel is driven by a pawl *9* carried by an arm fixed to the auxiliary shaft. This device causes the auxiliary disc to drive through the escapement wheel when the pointer is advancing across the scale but allows it to drop back freely to equilibrium when the load is reduced. Hence, the auxiliary disc will follow the variation in load while the demand pointer indicates its maximum deflection.

Time Element—The time required to reach equilibrium when any constant load is passed through the instrument is constant, since the deflection and rate of deflection vary in direct proportion. For example, suppose the instrument is so calibrated and adjusted that it requires 15 minutes to reach equilibrium when a constant load of 500 watts is passed through the instrument, then if we start again from zero and pass 1 000 watts through the instrument it is evident that the demand pointer must travel through twice the former arc, but since the main disc is rotating at double the former speed the pointer will reach equilibrium in the same time as it did before.

Mechanical Details—The meter has been designed so that it can be easily assembled, and all parts are readily accessible. It can be provided with either metal or glass cover. The base is of cast iron provided with separate terminal chamber, the meter movement being mounted on two bosses, cast in the case. The permanent magnets, electromagnets, disc and bearings are standard parts. A standard counter and dial are modified to provide the demand pointer. The auxiliary disc is a one piece punching made from a special alloy having a low temperature coefficient; it is readily accessible, by removing the four screws holding the electromagnet in place, and can be readily removed by loosening the top bearing screw. The escapement mechanism can be removed as a unit.

Capacities—The instruments are built in all standard capacities for single-phase and polyphase service, with one, two, five, fifteen and thirty minute time constants as desired. The time constant is determined by the gear ratio between gears *11* and *12*, Fig. 3. This is changed by simply changing the gears, the drilling being the same for all gear ratios.

The Calibration of the instrument is very simple. The main pawl is raised, thus cutting out the escapement and allowing the demand mechanism to respond instantly to the changes of load. The demand indicator is then calibrated as an indicating wattmeter by adjusting the length of the spring. A spring clamp and micrometer zero adjustment

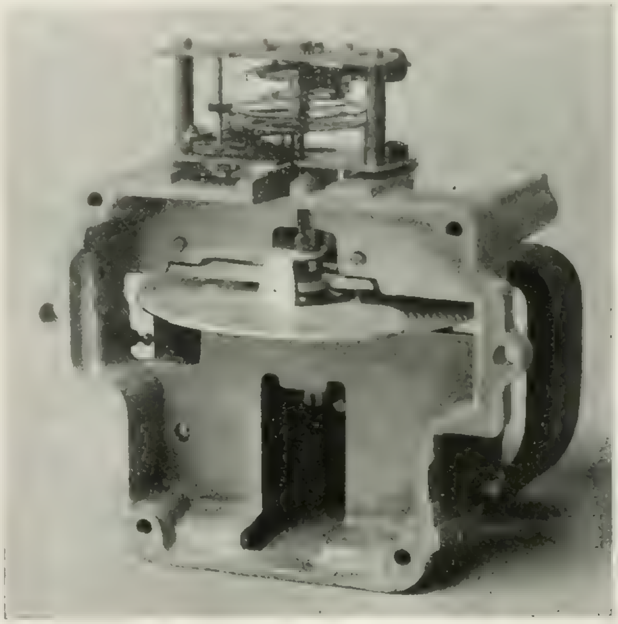


FIG. 7—REAR OF METER SHOWING AUXILIARY DISC CONSTRUCTION
Electro-magnets removed to show location of auxiliary disk. The magnets are standerd induction wattmeter magnets.

make this operation simple. The watt-hour meter is calibrated in the usual manner. The main pawl is then thrown down to engage its ratchet wheel. The zero stop is then adjusted so that the time is correct and the calibration is complete.

Large Turbine Alternator Units

C. N. Hardin and S. L. Henderson

DURING the last two years some very large Westinghouse turbine alternator units have been built; that is, units having maximum continuous ratings of from 10 000 to 21 000 kilowatts, have been completed or are under construction. In due time most of them will be subjected to steam consumption tests and, as their design progressively follows that of smaller machines whose efficiency has been thoroughly established, the builders believe, and preliminary tests on some of the units indicate that their high guaranteed performance will be more than fulfilled.

In general design, both the turbines and generators conform to the standard practice of the builders, differing from the smaller standard machines only in details of mechanical construction. The two parts of the units, the turbines and generators, will be discussed separately.

TURBINES

All of these turbines are designed for high-pressure steam expanding to high vacuum, the whole expansion taking place within a single casing. A great deal of attention has been given to the design of these machines in order to secure the utmost mechanical sufficiency, and much thought has been devoted to working out the details so as to insure continuity of service and to facilitate ease of operation. The excellence of any machine with reference to its successful or troublesome operation, rests very materially on the care given to its detail features.

The general construction and appearance of the turbines, as shown in Figs. 1 and 2, is typical of the combination impulse and reaction machines, which are now standard for all commercial sizes from 500 to 25 000 kilowatts capacity. This type of machine allows very compact construction and gives a very economical unit as regards both steam consumption and floor space. The combination blading is that best suited, so far as the steam volume is concerned, for the particular portion of the turbine where it is utilized. At admission to the turbine, the steam pressure is high and specific volumes small, so that the steam can be

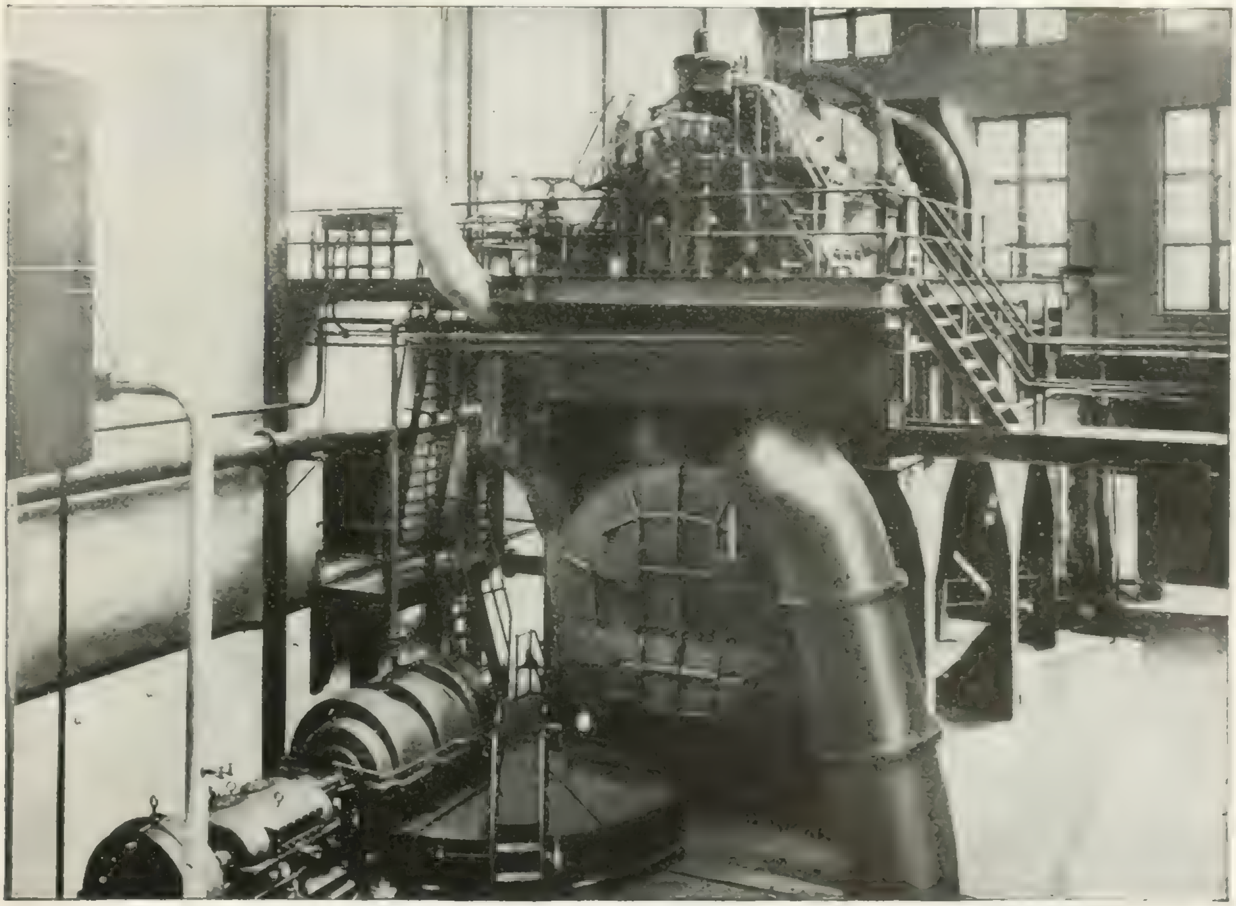


FIG. 1—A RECENT WESTINGHOUSE TURBINE GENERATOR INSTALLATION

20 000 k.v.a., 13 200 volt, 60 cycle, 1800 r.p.m. with a 25 000 sq. ft. surface condenser and a circulating pump of 37 500 gal. per minute capacity.

efficiently handled by impulse blading. The reaction blading required at this point would be quite short and so the leakage factor large and the blade efficiency low. When the capacity of the machine is great, thus demanding a large amount of steam, reaction blading may be efficiently used in place of the impulse element. After passing the impulse element the pressure is reduced, the specific volume increased quite appreciably, and so the reaction blading will be of such length as to be efficient. The low pressure blading in these machines is designed to utilize steam effectively at 29 inches vacuum, which extremely low exhaust pressure is desired and is obtained when the turbines are served by suitable condensing equipment.

As is appreciated, the turbine is inherently a high-speed machine and it is only limited in this respect by the mechanical construction of the turbine and generator. One of the chief problems, therefore, has been to design and construct the rotors of each element of the unit so as to permit of the efficient operating speed of the turbine. The turbine speed is of course limited in a way to the frequency desired, the maximum speed for 60 cycle operation being 3 600 r.p.m. and that for 25 cycle operation 1 500 r.p.m.

Due to the large volumes of steam handled in these units, necessitating large blade areas, the circumference of the blading must necessarily be quite large, requiring a large diameter which, if a speed of 3 600 r.p.m. for instance, were maintained, would give a peripheral speed higher than safely allowable for either the turbine or generator. However, the next lower speed, 1 800 r.p.m. for 60 cycle current, is permissible with these large units, as in 1 500 r.p.m. for 25 cycle current. Of the total number of machines only seven are for 25 cycle service, the balance being for 60 cycle, except in two instances where three units operate at 1 875 r.p.m. producing 62.5 cycles, and two operate at 2 000 r.p.m. producing 66.6 cycles.

The most notable part of the turbine is the spindle, Fig. 3. It is made up of five parts, an impulse element, two drums and two spindle ends. On account of the large capacities requiring large blade area at the low pressure ends, the low pressure drums operate at higher speeds than have hitherto been common practice, viz., 500 feet per second. Such speeds are entirely safe with ordinary materials by constructing the low pressure ends of what might be called a semi-disc form, which is made integral with the spindle end. This avoids the weakening effect of a hole in the disc or drum and provides a design of maximum strength, the stresses throughout being fairly uniform and within conservative limits.

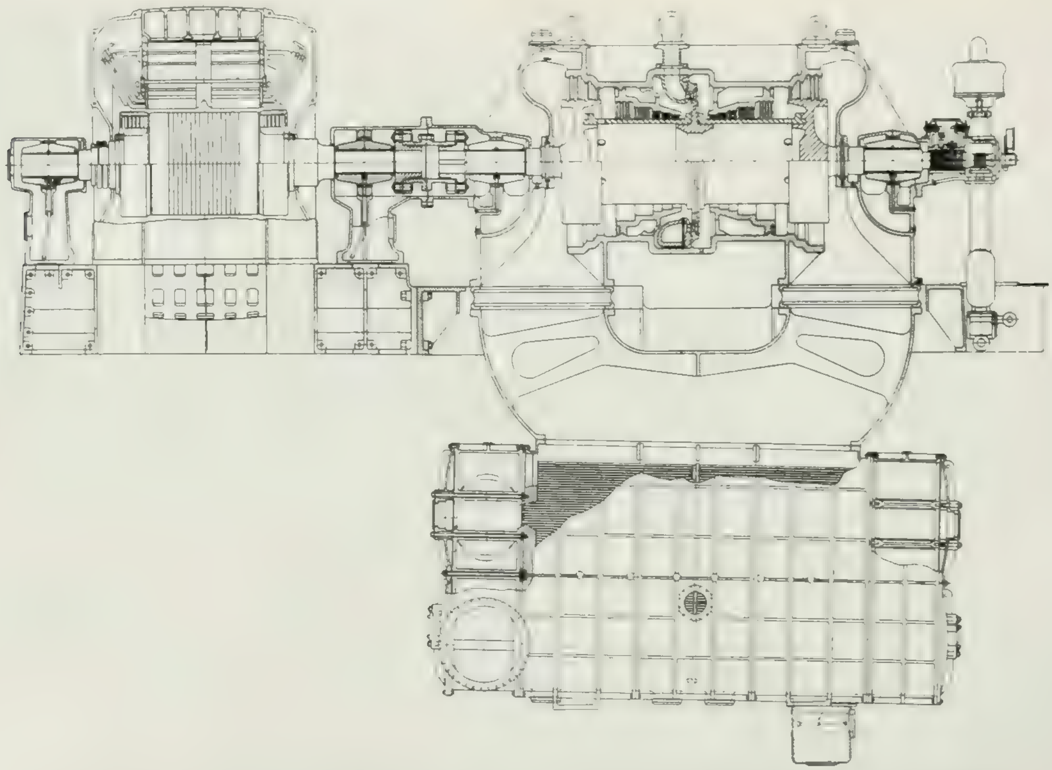


FIG. 2—SECTION OF INSTALLATION SHOWN IN FIG. 1, INCLUDING GENERATOR, TURBINE AND CONDENSER

As an assurance to the builder and customer that the spindle construction is safe and reliable, an overspeed test is applied to each turbine before it leaves the test floor. This test consists in operating the machine at 20 percent above normal speed, proving beyond any doubt that the blading and the spindle as a whole will not fail after it is installed. The turbine will not reach a greater speed than 8 percent above normal in commercial service, as the automatic stop is set to release at some such speed and the centrifugal type of stop used is absolutely reliable.

The turbine casing consists of only two parts,

commonly spoken of as the cylinder and cover. Fig. 4 shows the internal construction of a cover with respect to the blading and the stiffening or supporting stays in the exhaust ends. The material used in these castings is a high grade air furnace iron. The stays obviously are for strengthening the large exhaust ends. This style of stiffening is used rather than heavy ribs,

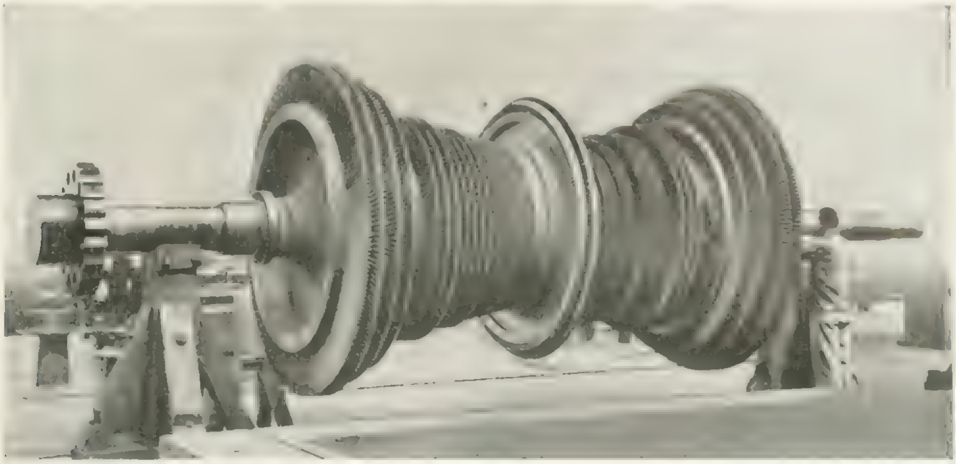


FIG. 3—SPINDLE OF A 20 000 KW, 15 000 R.P.M. TURBINE

as ribs are liable to cause internal strains as well as to increase the liability of imperfect castings.

Noting the method of retaining the blading in the cover (the same being true in the lower half of the casing or the cylinder) it will be seen that the last four low pressure rows are inserted in the cover casting proper, while the intermediate blading is held in a

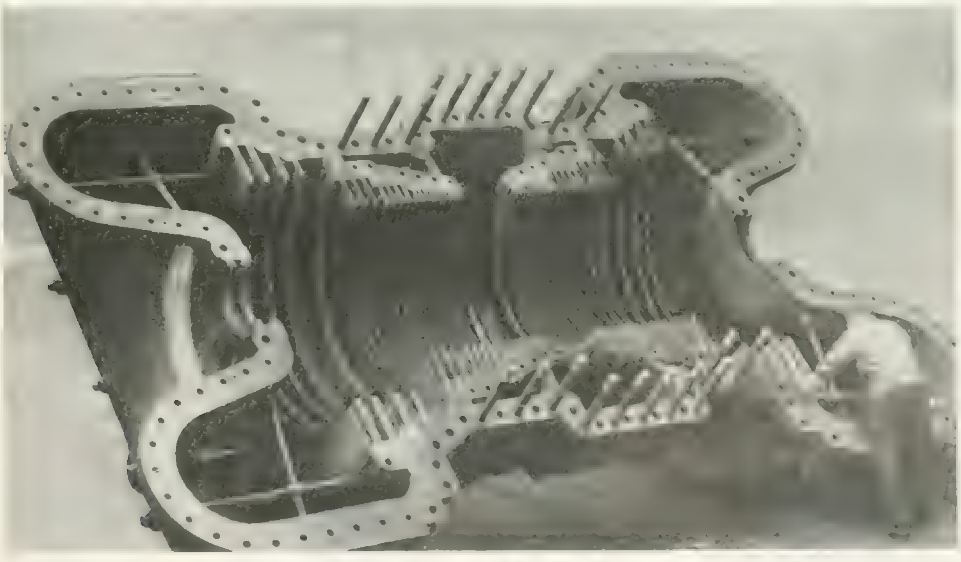


FIG. 4—TURBINE CASING FOR THE SPINDLE SHOWN IN FIG. 3

separate blade carrying element called the blade ring. There are several reasons why the blade ring is used:

1—It simplifies the main casting avoiding internal strains, assuring a better casting; 2—it lessens temperature troubles when the unit is in operation; and 3—it facilitates repairs to blading, as the blade rings are of standard size, and so as a whole can readily and quickly be replaced. Obviously the larger the turbine the greater the reasons for using the blade ring construction.

The details of these turbines, such as the governor, steam chest, valves, oil pump coupling, bearings, oiling system, etc., are the same general design as those used on the smaller machines.

The general trend today is toward maximum rated machines which, from the viewpoint of first cost, is very good; but generally speaking, the maximum rating of a turbine implies a rating at which the turbine economy is not the best, though the rating is generally only a few percent above the normal or economical rating. The majority of these twenty-three units were sold as maximum rated machines. However, a point to be considered is that a maximum rated unit is more flexible in operation; that is, it will operate safely as regards the generator temperature over a wider range of load, and the economy of the turbine over the same range of load is very good. One of these units approaches the ideal condition, consisting of a maximum rated generator with a normal rated turbine giving minimum first cost and maximum efficiency.

The steam economy of these large units is very good, for the turbine and also the generator efficiencies increase as the size of the unit increases, and the blade speeds of these turbines are quite high, giving a very efficient blade, since, as before mentioned, the turbine is inherently a high speed machine and so high blade speeds are necessary. The efficiencies guaranteed on two of the largest turbines when operating at common practice steam conditions, are around 73 and 71.5 percent for the 1 500 and 1 800 r.p.m. machines respectively. The reason for the difference is that the capacity is greater. By 73 percent is meant that the turbine utilizes effectively in producing power, 73 percent of the available energy in the steam and is 73 percent of the ideal. For the type of machine used these figures are very good. To show what figure is possible when the most economical design of machine is used, considering efficiency as the prime requisite, better than 79 percent turbine efficiency was guaranteed on three 30 000 kw units recently sold. In these turbines only reaction blading is used.

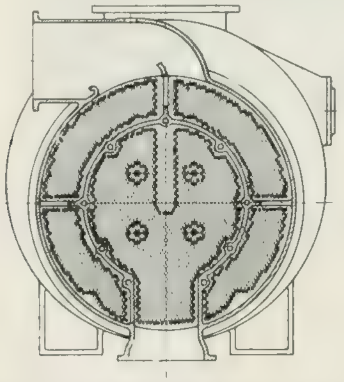


FIG. 5—SECTION OF SURFACE CONDENSER SHOWING STANDARD ARRANGEMENT OF TUBES

FLOOR SPACE

The floor space occupied by turbine generator units is very small compared with that occupied by other types of prime movers. The unit floor space, which is taken as the square feet of floor space per kilowatt capacity, decreases as the size of the unit and rotative speed increases. To show some actual figures, two units of 15 000 and 20 000 kw maximum rating operating at 1 800 and 1 500 r.p.m. respectively are compared in Table I. For floor space, that area included within the floor plates, which extend out beyond the bed plate three or four feet on every side are taken as the basis of comparison.

TABLE I—COMPARISON OF FLOOR AREAS

Rating Kw	Speed R.p.m.	Length and width	Floor space sq. ft. per kw
20 000	1500	46′ 2½″ by 21′ 1½″	0.0488
15 000	1800	41′ 11″ by 19′ 2½″	0.0537
9 000	1800	36′ 1½″ by 16′ 8″	0.067
5 000	1800	34′ 11″ by 14′ 4″	0.10
5 000	3600	30′ 8″ by 13′ 3½″	0.08
1 000	1500	31′ 3″ by 9′ 0½″	0.28
1 000	3600	23′ 0″ by 8′ 3″	0.20

To be more conclusive some smaller capacity machines were also included in the table.

WEIGHT

The weight of a turbine generator unit obviously increases with the capacity, but not in direct proportion as the unit weight becomes less as the capacity increases. Another factor affecting weight is rotative speed; the higher the speed for a given capacity the less the weight. This fact is more pronounced with the turbine end of the unit than with the generator, the turbine weight decreasing proportionally more than that of the generator. So the 1 500 r.p.m. outfit, due to its lower speed, as well as being of a more rugged design than the 1 800 r.p.m. unit is a relatively heavier machine, as shown in Table II.

SURFACE CONDENSER

The larger the power plant the greater the attention paid to everything pertaining to it, and the question as to the type of condensing equipment to be used, whether jet or surface, is carefully considered from every viewpoint. Due primarily to the conservation of the condensate for boiler feed purposes and the relatively cheap and abundant supply of cooling water, nearly all of the large turbines are served by surface condensers. Of these turbines, eighty percent are equipped with Westinghouse condensers, only four being of the jet type, and they are used with four of the smallest turbines. The surface condensers supplied vary in size from 15 000 to 30 000 square feet. It may be noted that three 50 000 square feet surface condensers have also recently been sold, these being the largest surface condensers that have ever been built.

The general shape of these large surface condensers is circular in cross-section, except in special cases where the rectangular shell was desired. The standard arrangement of tubes in the shell is shown in Fig. 5, the radial flow principle being used, the steam flowing around the whole circumference of the tubes and in toward the center along radial paths.

TABLE II—COMPARISON OF WEIGHTS

Rating	Speed R p m	Weight Pounds	Pounds per sq. ft. of floor area	Pounds per Kw
20 000	1500	660 000	677	33.0
15 000	1800	450 000	560	30.0
5 000	1800	220 000	440	44.0
5 000	3600	180 000	450	36.0

This type gives minimum drop in pressure through the condenser as the distance the steam has to pass through the tube space is a minimum, and the steam velocity is less due to the increased admission area. The condensers are of the two pass type, the cold water flowing through the center tubes and the warm water returning through the outer tubes, or vice versa, whichever is desired.

This type of surface condensers has revolution-

ized surface condenser practice, as the unit heat transfer obtained is very high and the drop in pressure through the condenser in all instances is so small as to be practically negligible. The very good performance is largely due to the Leblanc air pump, which maintains a very low air tension in the condenser, which, however, is only possible by adhering to the correct design of condenser throughout.

The auxiliaries, the circulating, condensate and Leblanc air pumps are all of the rotary type and built by the condenser builder. The large condenser pumps are all separate units, each being driven by a small non-condensing turbine or motor if preferred. The turbine drive is almost invariably used as there is of necessity, from the economical viewpoint, a certain amount of steam needed to heat the feed water, and if the plant auxiliaries (including the condenser pumps) are driven by non-condensing turbines their exhaust steam, in a well designed plant, is just about sufficient for this purpose.

and that the energy is being generated in a comparatively small volume, it is seen that very effective ventilation is necessary to dissipate the heat in order to maintain safe operating temperatures.

The axial type of ventilation has been found to be the most effective method for cooling these large machines. In the method adopted, the air enters at both ends of the machine and flows towards the center in three parallel paths, i. e., along ducts in the stator parallel to the axis, through the air-gap, through ducts in the rotor, and then out at the center of the machine through one or more radial ducts. One hundred cubic feet of air per minute per kilowatt loss is a rough figure for the air necessary to conduct away the heat, and in a generator of approximately 600 kw loss would mean 60 000 cubic feet of cooling air per minute. The total duct area on these machines, taking account of the fact that the air enters from both ends, ranges from 15 to 20 square feet.

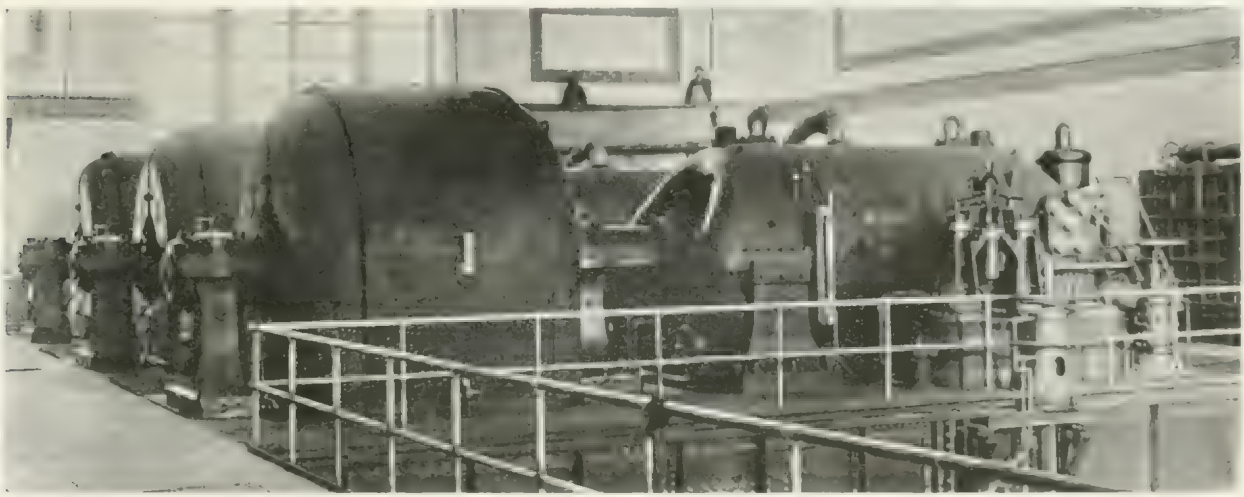


FIG. 6—AN INSTALLATION OF THREE 18 750 KV-A, THREE-PHASE, 62.5 CYCLE, [illegible] VOLT, 1875 R.P.M. TURBO UNITS

The circulating pumps for these large units are, owing to their size and capacity, slow speed machines, and so for efficient operation a reduction gear is interposed between the turbines and the pumps. The air and condensate pumps, however, can operate efficiently at the high turbine speed and so they are direct-connected. As the size of condenser is decreased the pumps become smaller, permitting the circulating pump to operate at the turbine speed and so different arrangements as two or even all three of the pumps on one shaft and driven by a single turbine may be used.

THE GENERATOR

One of the big problems in the generator design was to get sufficient air through the machine to carry off the heat represented by the losses. This was a problem not only of getting air through the machine, but it was also necessary to obtain sufficient radiating surface. When it is realized that the total losses, including air friction, amount to 500 or 600 kilowatts

which means average air velocities of from 3 000 to 4 000 feet per minute, although in restricted places the velocity is higher. In general, there is sufficient radiating area, including vent duct and air-gap surface in the stator, to radiate approximately two watts per square inch. These units are operated in conjunction with separately driven fans and, in general, use is being made of some type of air washing or air cleaning apparatus.

Another feature in these large machines that has received considerable attention is their ability to operate satisfactorily under sudden short-circuits. This has been taken care of in the design of the generator in the shape of the coil at the end, which in itself tends to resist being pulled out of place and also in the very rigid coil support used. This support consists of a number of iron coil supports bolted securely to the frame. To these the coils are firmly fastened and the coils, to prevent movement among themselves, are held firmly apart by bronze separators.

The development of these large machines was a step far in advance in the art and very complete and thorough tests were made. Every precaution known at the present time has been taken in the design of the large turbo-generator and the manufacturing company has tested the machines thoroughly in the factory whenever it has been possible. It may not always be possible to make complete tests on a generator, because such features as voltages and frequencies which are not standard may, perhaps, make such testing difficult. As an illustration, however, of the magnitude of the work done in the way of testing such large generators, a number of machines that have been built and on which very thorough tests have been made at each rating, are listed in Table III.

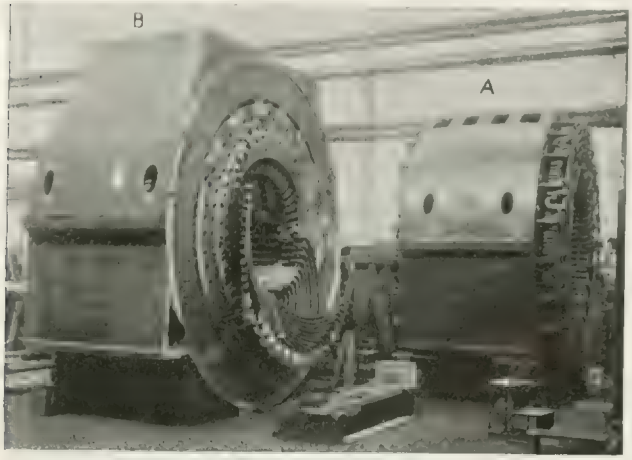


FIG. 7—A 7 500 KW GENERATOR AT *a*, AND AT *b* A 20 000 K.V.A. GENERATOR

TABLE III—CHARACTERISTICS OF MACHINES TESTED

Kilovolt Amperes	Volts	Phase	Cycles	R.p.m.
12500	6600	3	66⅔	2000
12500	2300	3	60	1800
12850	2300	3	60	1800
13150	4800	2	60	1800
18000	12000	3	60	1800
19000	2700	3	60	1800
19000	8000	3	62½	1875
20000	13200	3	60	1800
11250	11000	1	25	1500
15800	13200	3	25	1500
*21000	6600	3	25	1500
*21000	11000	3	25	1500

*Too large to be shipped completely assembled and tests made on rotor only.

The valuable experience gained from the tests on so many generators of such varied characteristics puts the 20 000 k.v.a. generator beyond the period of experimentation. These tests have been most thorough and complete, in fact much more so than would have been possible if the tests were made outside the factory where facilities are not available and where the designers cannot follow the tests as closely. They have included the electrical tests of losses, temperature tests and short-circuit characteristics and those dealing with the mechanical side including overspeed test, tests for the effect on the winding of short-circuits, and tests of the raw material going into the machine. The temperature test must, of course, be a compromise one as it is impracticable to load directly such large units. This compromise test is generally a zero power-factor run with over-excited field which is a test under more severe conditions than the machine is to meet in actual service. Where a separate blower is used the test is made in conjunction with this apparatus.

An excellent illustration of the advance in turbo-generator design is given in Fig. 7. On the right at *A* is a 7 500 kw, 750 r.p.m., 25 cycle generator of early design, and on the left at *B* a generator of approximately 20 000 k.v.a., 1 500 r.p.m., 25 cycles in the process of construction. The overall dimensions of these two machines are practically the same with the exception that the outside width and height of the frame of the new machine is approximately six inches more than the old. This increase in rating for practically the same volume has been possible because of the experience gained in the manufacture of such a large number of large capacity generators. Many points of improvement can be noted in the new machine, such as the shape of the coils, more efficient bracing of the coils, and the ventilating ducts through the stator core.

In this article no attempt has been made to describe the details of the construction of these units as much could be written on each machine in itself. While the building of these units required much pioneer work, nevertheless, because of the long experience of the manufacturers in the building of turbine generator units, it was possible to anticipate many of the difficulties. The development has been a process of evolution and with greater knowledge has come greater possibilities. Many, perhaps, have not realized the magnitude of the work accomplished and the number of these large units built and in successful operation, and it was thought that a brief resumé of the field might prove helpful.

Street and Industrial Lighting Units

G. W. Roosa

THE EFFICIENCY of light production is the most important element entering into the problems of lighting by electricity. In all classes of illuminants there have been great improvements in efficiency in the past ten years. In general this is the result of two things: first, the study of selective radiation from materials at incandescent temperatures and the application of these principles were in their infancies ten years ago; second, the efficiencies of the earlier generators, motors or transformers were much closer to 100 percent than those of the electrical illuminants. The nature of the latter is such that a very high efficiency is not attainable and until recently even a true measurement involved difficult calculations. The efficiency of electrical apparatus, such as generators, motors and transformers, is between 85 and 98 percent, but that of the production of light is in the neighborhood of five percent. The latter figure is based on the actual electrical energy supplied to the lamp as compared with the energy-equivalent secured in visible radiation.

FIG. 1—ILLUMINATION OF A BUSINESS STREET BY ARC LAMPS

A consideration of illumination problems involves efficiency first, since with high initial efficiencies a means is afforded of overcoming all other objectionable characteristics. For instance, in the gas filled incandescent lamp, high efficiency runs hand in hand with high intrinsic brilliancy, which is detrimental. By enclosing this lamp with diffusing glassware, the high brilliancy is eliminated at a loss of useful light; in other words, a reduction in efficiency. Still the loss is negligible as the initial efficiency is very high. Thus a desirable type of lighting unit is secured at a reasonable intrinsic brilliancy with a higher ultimate efficiency than is obtained with vacuum incandescent lamps.

In practical work, two distinct classes of problems occur, the principles of high efficiency, however, being applicable to both. The lighting of streets and the illumination of industrial plants (or indoor lighting) are different in many respects. Each individual problem of these two classes requires a solution of its own. Street lighting, however, cannot be standardized into stereotyped solutions, as areas, mounting heights and many other variations make it difficult to predict the results, which are readily predetermined in indoor problems.

STREET LIGHTING

The requirements of street lighting in general are classified into those for business districts, residential districts and outlying territories. The present lighting units which are available for these purposes are shown in Table I. In street lighting it is primarily desired to produce with the least cost a fairly uniform and sufficiently intense illumination on the street without excessive glare. The cost includes the cost of energy and maintenance, and the interest and depreciation on lamps, station apparatus, poles and auxiliary equipment. In all cases the intensity of illumination is dependent upon the spacing distances and the mounting heights of the lamps, the design of glassware or reflectors used and the wattage and the distribution of light from the lamp. On account of the fact that the distance between lamps is commonly much greater than for indoor lighting, a lamp must distribute its maximum candle-power at relatively small angles below a horizontal plane through the source of light so that points midway between the lamps will receive sufficient illumination. In a great many cases in dim light it is impossible to see objects by the direct light thrown on them but they appear as a silhouette against a lighter background. This principle

is made use of in lighting residence streets. In business sections, window lighting and electric signs along the street are, quite often, sufficient to reduce the general requirements for the street to such an appreciable extent that only enough light need be furnished to light the way for drivers and pedestrians after the end of business hours, when window lights, display lights and electric sign lighting are all turned off.

In the business sections of large cities, the illumination should be more or less brilliant, as illustrated in Fig. 1, as uniform as possible and of sufficient intensity to aid in preventing congestion of heavy traffic. The type of lamp and means of suspenson should be of a pleasing design so that it will not detract from the daylight appearance of the street.

To light residence streets properly, a great amount of light is not required, but the general illumination should be such as to enable one to consult a notebook for an address or to distinguish house numbers. These streets are usually narrow and densely shaded, thus the lamps must be mounted low, with fixtures of the general type shown in Fig. 2, and lamps of low intrinsic brilliancy.

FIG. 2—MAZDA STREET FIXTURE WITH CONCEALED WIRING

TABLE I—TYPES OF ELECTRIC ILLUMINANTS

1—*Vacuum Type Mazda Lamps (series):*
- 3.5 amperes—32, 40, 60 and 80 candle-power.
- 4.0 amperes—32, 40, 60, 80, 100, 200 and 350 candle-power.
- 5.5 amperes—32, 40, 60, 80, 100, 200 and 350 candle-power.
- 6.6 amperes—32, 40, 60, 80 and 100 candle-power.
- 7.5 amperes—32, 40, 60 and 80 candle-power.

2—*Gas Filled Mazda Lamps (series):*
- 6.6 amperes— 80, 100, 250, 400 and 600 candle-power.
- 7.5 amperes— 80 and 250 candle-power.
- 20 amperes—400, 600 and 1 000 candle-power.

3—*Metallic Flame Arc Lamps:*
- 4.0 amperes—D.C. series 272 watt lamp.
- 6.6 amperes—D.C. series 450 watt lamps.

4—*Flame Carbon Arc Lamps:*
- 6.6 ampere, 7.5 ampere, 10 ampere, A.C. series lamps, 445 watts.
- 10 ampere A.C. 110 volt multiple lamp, 500 watts.
- 6.5 ampere D.C. 110 volt multiple lamp, 715 watts.

From Table I it will be seen that the vacuum type Mazda lamp is available for all kinds of lighting problems, but is best adapted to residence and interior lighting of buildings with low ceilings. The use of this lamp in clusters on ornamental standards for business section lighting is giving way to the flame carbon pillar and bracket ornamental lamps, such as shown in Figs. 3 and 4, which are more efficient and economical.

ARC STREET LIGHTING

The maintenance and operation costs of tungsten cluster lighting for this class of street as compared with the costs of high efficiency arcs, is such that when equal illumination is secured the expense of the former system is prohibitive. On the basis of an equal number of units the flame carbon pillar lamp gives four or five times the illumination of a tungsten cluster, consisting of one 100 watt and four 60 watt lamps.

FIG. 3 — PILLAR TYPE FLAME CARBON ARC LAMP ON A 14.5 FOOT ORNAMENTAL PILLAR

A great many enclosed carbon arc lamps are in use now, but they are rapidly being replaced by the four ampere metallic flame arc lamp, such as shown in Fig. 5, which has higher efficiency, lower maintenance cost and distributes the maximum light at an angle of about 10 degrees below the horizontal, which makes it an excellent street lamp. It is designed for two standard current ratings of 4 and 6.6 amperes and in both cases requires about 68 volts per lamp. The efficiency is between 0.45 and 0.55 watts per mean lower hemispherical candle-power. This is distinctly a direct-current lamp and operates in series on constant-current circuits supplied from constant-current generators or rectifiers. It burns a one-half by 16 inch homogeneous upper electrode of metallic oxides consisting of magnetite titanium and chromium and a lower electrode or button composed of iron and copper. The light produced is white and approaches that of sunlight. The life of each trim of electrodes is from 250 to 300 hours in the four ampere lamp and from 115 to 150 hours in the 6.6 ampere lamp. During this life a small quantity of soft red ash, commonly called soot, accumulates in the bottom of the globe. This, however, does not detract from the illumination on the street because the lamp is so ventilated as to keep the globe clean. The soot is readily removed by dumping it out of the globe and by running a brush up through the chimney of the lamp.

The usual station equipment for a metallic flame street lighting equipment consists of a constant current rectifier regulating transformer, as shown in Fig. 6, and a suitable control panel. The efficiency of such a system at full load is about 92 percent and the power-factor is about 65 percent. Direct-current

arc machines of proper current capacity can be used instead of the constant-current rectifier if available, but at considerably reduced efficiency from that indicated above. Station equipments for metallic flame arc lamps can be obtained for operation on any frequency from 25 to 60 cycles and in 25, 35, 75 and 100-light capacities and for almost any primary voltage between 1 100 and 13 200 volts.

FIG. 4—WHITE WAY FLAME CARBON ARC LAMP ON ORNAMENTAL BRACKET

FIG. 6—50-LIGHT CONSTANT-CURRENT [illegible] RECTIFIER FOR METALLIC FLAME ARC LAMPS

The most efficient illuminant for street lighting is the long burning flame carbon arc lamp, on installation of which is shown in Fig. 7. When this lamp is mounted at 22 to 27 feet above the pavement clear glassware can be used, and a very good distribution of light results. Under these conditions, the efficiency is better than 0.3 of a watt per candle-power and the maintenance cost is lower than that of the high efficiency gas filled lamps which give practically the same number of lumens. The alternating-current series lamp which operates at ten amperes and 45 to 50 volts at the arc, and consumes 445 true watts at the lamp terminals, is best adapted for street lighting. The efficiency of light production is approximately 0.32 watts per mean lower hemispherical candle-power when white light carbons and clear globes are used, as shown in the illumination curve, Fig. 9. The maximum candle-power is distributed at five to ten degrees below the horizontal when clear globes are used and at 30 to 40 degrees when Alba outer and clear inner globes are used. Impregnated flame carbons, seven-eighths of an inch in diameter and 14 inches long are used, giving a life of 110 to 150 hours per trim. Either white or yellow light-producing carbons are available, although the white light carbons are more suitable for street lighting. Flame carbon lamps can be obtained for all commercial cir-

FIG. 5—TWO METALLIC FLAME ARC LAMPS ON POLE

FIG. 7—INSTALLATION OF FLAME CARBON ARC LAMPS

cuits, both alternating and direct-current, and in either suspension or pillar type design. The performance of the two types are practically the same, since the mechanism of the pillar lamp is the same as that of the suspended type with but a few minor changes to adapt it to the pillar mounting. Comparative electrical and illuminating performances of some of the present types of arc lamps are given in Table II.

FIG. 8—NIGHT ILLUMINATION ON A BUSINESS STREET LIGHTED BY SERIES FLAME CARBON ARC LAMPS

The necessary station equipment for a circuit of flame carbon lamps consists of a constant-current regulating transformer and suitable control panel. The full-load efficiency is about 95 percent and the power-factor is approximately 60 percent. Constant-current regulators can be obtained for 6, 12, 18, 25, 35, 50, 75 and 100-light capacities and for primary voltage up to 11 000 volts.

INCANDESCENT STREET LIGHTING

Mazda lamps are of two distinct types, which for convenience are designated as vacuum Mazda and gas

TABLE II

Type of Lamp	Arc Amps.	Terminal Volts	Terminal Watts	Mean Lower Hemis. Cp.	Watts per Mean Lower Hemis. Cp.
D. C. open	9.6	50	480	840	0.57
D. C. enclosed......	6.6	75	480	466	1.03
D. C. met. flame...	4.	68	272	495	0.55
D. C. met. flame...	6.6	68	449	980	0.46
A. C. enclosed	6.6	76	411	210	1.96
A. C. Series Flame Carbon..	10.	55	445	1400	0.317

Note—The values given in above table and curves are only approximate.

filled Mazda lamps. The latter have been recently placed on the market in this country and for this reason actual operating data is not available. The efficiencies vary from 0.75 to 0.5 watts per mean horizontal candle-power depending upon the size of the lamp. The present difficulty with the gas filled lamps is that they run extremely hot and it is necessary to protect them by enclosing cases when they are operated outdoors. Due to the fact that these lamps have a very high intrinsic brilliancy (in the neighborhood of the intrinsic brilliancy of the yellow flame carbon arc) they should, if mounted low, be enclosed in a diffusing globe in order to reduce the glare effect.

Many designs of series Mazda lamp street hoods, such as shown in Fig. 10, are available for both the vacuum type and the gas filled type of lamp. For

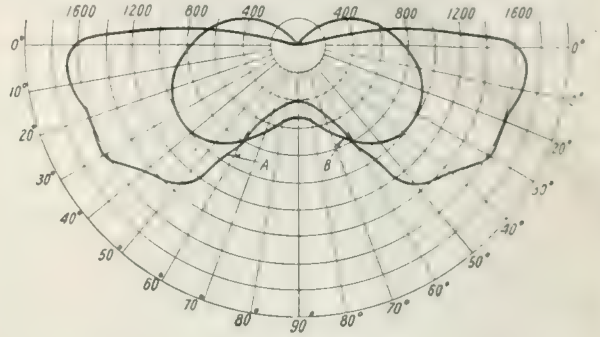


FIG. 9—DISTRIBUTION OF LIGHT FROM AN ALTERNATING-CURRENT FLAME CARBON ARC LAMP

A—Clear outer globe.
B—Alba outer globe.

street lighting purposes most lamps are operated on the constant-current regulator system, but many installations are on constant potential. In the latter case, what is known as the adjuster socket system is used, a transformer or auto-transformer supplying a constant current from a constant potential through the use of shunt reactance coils. A study of Figs. 11, 12 and 13 gives a good idea of the adjuster socket system, which works in the following principle:—

A reactance coil is shunted across each lamp, its characteristics being such that when the lamp is burning only a very small magnetizing current is taken, which is nearly 90 degrees out of phase with the lamp

FIG. 10—MAZDA STREET HOOD FOR CABLE SUSPENSION

current. When the lamp is burned out, the entire current is forced through the reactance coil, whose impedance, due to the change in phase relations, is then approximately equal to the previous combined

impedances of the coil and lamp. This reactance is about three times as large as the lamp resistance, and is an average value; for the first few coils to be cut in should have a little higher value to keep the impedance large enough, and those cut in after about 30

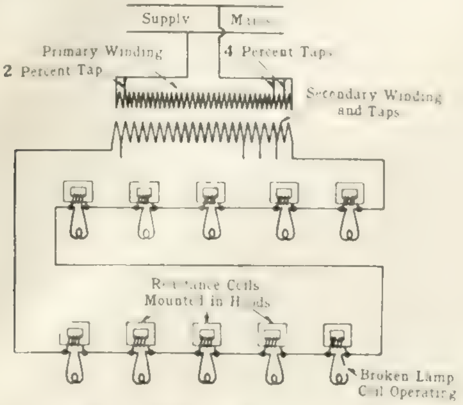


FIG. 11—ADJUSTER SOCKET SYSTEM SHOWING OPERATION OF REACTANCE COILS TO REPLACE LAMPS

percent outage should have less to keep the impedance down, but as it is impossible to predict which coil will operate first, an average value, one that will keep the highest rise below 3.5 percent, is necessary. As the outages increase the current wave form becomes distorted, which decreases the reactance in the circuit and the impedance does not increase as rapidly as at first, thus tending to maintain the current value and accounting for the peculiar turn the curves take for the different wattage coils after the outage reaches 40 or 50 percent. The curve given in Fig. 13 is an average curve for reactance coils of various wattages. As a rule very low outage is experienced in actual practice with the adjuster socket system as the patrol systems of most central stations eliminate high outage.

The gas filled Madza lamp is gradually finding its place in street lighting, but at present is used only in small installations. The necessity for large currents and the problem of dissipating the heat generated seems to be limiting its use. However, its introduction into general use will result in better incandescent lamps and improved arc lamps. Each lamp will have an application to which it is best fitted.

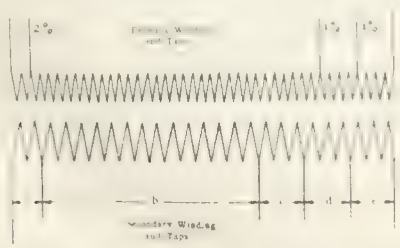


FIG. 12—ARRANGEMENT OF TAPS ON SPECIAL TRANSFORMER FOR USE WITH THE ADJUSTER SOCKET SYSTEM

Further increases in efficiency will be more readily attained in the arc lamp than in the incandescent lamp.

CURRENT REGULATORS

Air-cooled constant current regulators for arc lamps and tungsten series systems have also undergone improvements. The old pancake-shaped coil type has been superseded and regulators with ventilated coils, as shown in Fig. 14, are designed for 6.6 amperes or 7.5 amperes as well as 10 amperes for flame carbon arcs. Operating companies can use regulators for either arc or incandescent lamps with very small changes. In systems where the larger percentage of the lamps are incandescents a dash pot is not necessary, but where more than 20 percent of the voltage is consumed by arc lamps, a dash pot is necessary. The coils are wound in two layers of rectangular wire per coil in the large sizes, and round wire in the small sizes. One edge of the cotton covered wire is exposed to air, except where protection is necessary in bringing out leads and where the outside and the inside coils are close to the core. The regulators have taps available on 2 200 volt windings to give normal operation on 2 400 and 2 000 volts. This arrangement makes it possible to obtain full-load

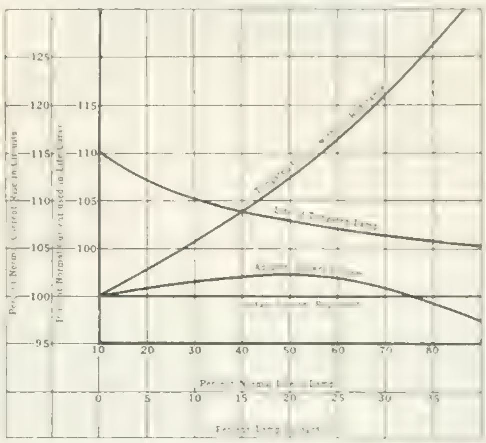


FIG. 13—CURVES SHOWING CHARACTERISTICS OF ADJUSTER SOCKET SYSTEM

power-factor on voltages somewhat higher or lower than 2 200 volts.

As a result of the use of ventilated coils much lower temperature rise is experienced, thus making it possible to use them in very warm localities. The air circulates freely about the coils and hot spots which may endanger the insulation are eliminated, as the coils are never over one-half inch in thickness.

INDUSTRIAL LIGHTING

For industrial lighting there are as many lighting units available as for street lighting. Combinations of Mazda and arc lamps with various reflectors and globes are designed for all common industrial and power circuits. The following lamps are available:—

1—Vacuum Mazda lamps.
2—Enclosed carbon arc lamps (mill type).
3—Gas filled Mazda lamps.
4—Flame carbon arcs.
5—Vapor tubes.

The problems to be met in industrial lighting are much the same as those for store and office lighting. Given areas with given ceiling heights have made it possible to standardize on lamp sizes and reflectors

thus enabling the layman to plan lamp locations which will give a predetermined average illumination on the working plane. Most industrial plants have high roofs and cranes from 25 to 50 feet above the work

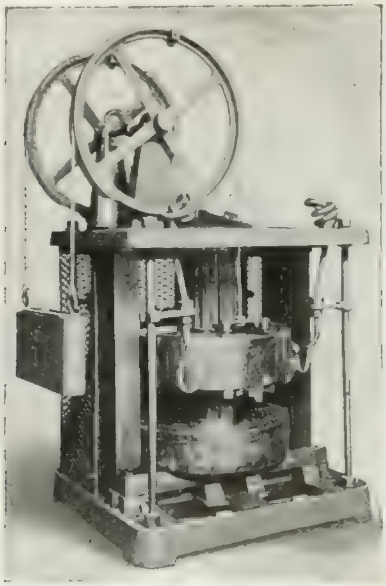


FIG. 14—WESTINGHOUSE CONSTANT-CURRENT REGULATING TRANSFORMER FOR MAZDA LAMPS OR FLAME CARBON ARC LAMPS (ONE-HALF OF COVER REMOVED)

being done. Here the use of incandescent lamps is seldom satisfactory. Flame carbon arcs with or without reflectors are commonly employed, a typical example being shown in Fig. 15. The distribution of

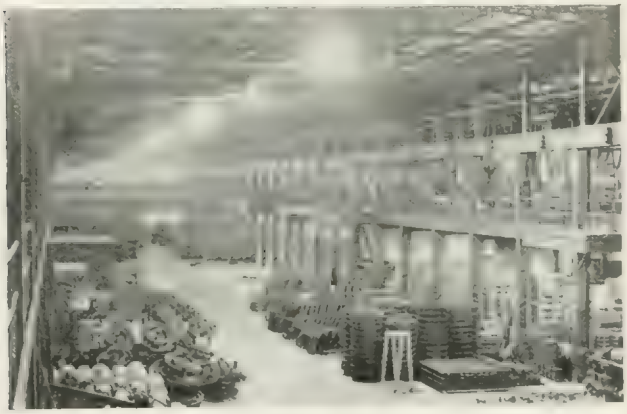


FIG. 15 ILLUMINATION OF INDUSTRIAL PLANT BY FLAME CARBON ARC LAMPS

light may be concentrated as shown in Fig. 16. This reflector is attached to the bottom of the condenser chamber and no outer globe is necessary. For this class of lighting the flame carbon arc is most economical and the long life of the carbons, 110 hours, insures a minimum of outages for trimming during working hours. Many plants are installing the 110 hour lamp in place of the open flame arc with a reduction in maintenance and operation costs sufficient to more than pay for the lamps in ten months. The average cost of carbons and trimming labor on open flame carbon arcs is about $55 per lamp year as against $8 per lamp year for the long burning lamp.

Large sizes of gas filled tungsten lamps with suitable reflectors will be used to some extent for lighting in high bays, but give lower efficiency and higher renewal costs for an illumination equal to that of a flame carbon arc installation.

In some cases of industrial lighting low ceilings exist, and vacuum Mazda lamps of small candlepower, closely spaced, give excellent illumination. For such installations the initial costs of wiring, sockets

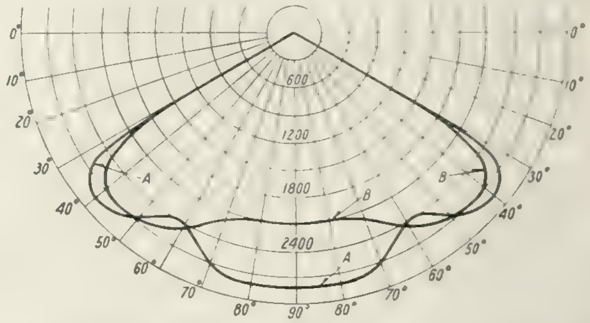


FIG. 16—CURVES SHOWING CONCENTRATION OF LIGHT FROM FLAME CARBON ARCS EQUIPPED WITH REFLECTORS FOR INDUSTRIAL PLANT LIGHTING

A—Alternating-current multiple arc.
B—Direct-current multiple arc.

and reflectors is high. The wattage per square foot is also higher than in the larger bays where carbon lamps can be used.

In the average industrial plant 220 volts direct current or 110 volts alternating current, is the common service. For 220 volt direct-current circuits the multiple series flame carbon arc is often used as a so-called "power circuit" lamp. It is so designed that either two or four lamps can be operated in series on constant potential. If one lamp burns out the remainder continue to operate, as each lamp is constructed with an internal substitutional resistance which takes up the voltage that was consumed by the lamp.

Improving Air Conditions

E. E. GARLITS

THAT the air in which we live and breathe should be absolutely pure, all agree. Such a condition, however, is ideal and is never reached except in the "great out doors." In towns and cities pure air seldom exists, due mostly to accumulations of smoke, fumes, odors, etc., given off by manufacturing processes. Added to all these is the exhaled air of animals and persons, containing besides carbon dioxide large quantities of decomposing organic matters. In large cities, the proximity of buildings prevents the natural circulation of air and the almost total absence of plant life prevents the absorption of carbon dioxide that would ordinarily take place. In confined places where people gather, these conditions are greatly intensified, so much so that they form a serious problem and make it absolutely necessary to resort to some plan for the removal of vitiated air, or

FIG. 1—TYPICAL INSTALLATION OF VENTILATING FANS IN A MOVING PICTURE THEATRE.

the destruction of the harmful substances which it contains. During the warm summer months the foregoing conditions are intensified and, even if the air should not be vitiated, the oppressiveness of close, heated interiors becomes unbearable. To alleviate these conditions the small portable and non-portable fans have been introduced and the judicious use of these "buzzy bodies" goes a long way toward making the many millions of our cities cool and comfortable, whether at work or at rest.

Fan motors, according to their application, are divided into two classes. First, those which remove or exhaust vitiated air and are commonly called exhaust or ventilating fans. Second, agitation fans made in desk and bracket and ceiling types and which are most commonly used. These fans do not exhaust, but stir up or agitate the air. They may, however, be so directed as to aid in directing the air currents toward exhausting fans but their effectiveness is not materially lessened if this is not always done.

EXHAUST OR VENTILATING FANS

Exhaust or ventilating fans are less common than the desk, bracket and ceiling types. This is probably because they do not cool the air and are therefore not so readily appreciated. This, however, does not indicate that they are not as useful, for it is absolutely necessary that the vitiated air in such places as theatres, nickelodeons, kitchens and places of like character be removed. As previously stated, this exhausting of vitiated air does not produce cooling unless the air coming in to replace that exhausted is cold and this is seldom possible.

Small exhaust fans for installations of this kind are from 12 to 16 inches in diameter and can be operated from the usual lighting circuit and controlled by a snap switch. They are easily mounted in a wall or partition but should not be operated against pressure or through a flue over one foot in length. If intake or exhaust pipes are unavoidable, they should be made as short as possible and bends or turns avoided.

TABLE I—FRESH AIR REQUIRED PER PERSON.

Application	Cu. Ft. per Minute
Theatres....	[illegible]
Work shops....	[illegible]
Nickelodeons	[illegible]
Offices .	[illegible]
Schools	[illegible]
General hospitals	[illegible]
Kitchens . . .	[illegible]
Contagious hospitals....................	80

An excellent plan for installing exhaust fans in the ordinary nickelodeon is to provide two openings for each fan, one near the floor and one near the ceiling. During the winter months the fan is mounted in the opening near the floor and thus removes the heavy odors without removing the warm air and overtaxing the heating equipment. During the summer the fans are placed in the openings near the ceiling and exhaust the warm, stuffy air which collects rapidly near the ceiling at this time. Where provision cannot be made for two locations, the one near the ceiling is preferable.

In determining the size and number of exhaust fans required for the common installations, Table I will be useful. These figures indicate the quantity of air necessary per minute per person and it is therefore not necessary to consider the cubical contents of enclosures when using this table.

Knowing the average number of occupants in any case, the total quantity of air required is readily calculated. Then, as manufacturers always specify the cubic feet of air delivered per minute by the various fans and, keeping in mind that the air should not be changed more often than once in five minutes to avoid creating objectionable draughts, it is comparatively simple to calculate the number and size of fans required. In determining the number of fans required, sources of natural ventilation, such as skylight windows and doors should not be overlooked, as these generally reduce the number of fans theoretically required by one third to one half. No more than six 16-inch fans should be recommended for any one installation and where more than this number are required fans of larger diameter should be resorted to.

Fans should not be arranged to draw the air inward to replace that exhausted. If this is done, draughts will be created which are objectionable. The air coming into the room should be allowed to come freely and care should be taken to see that it comes from a pure source and, of course, through openings near the floor provided for that purpose.

To reduce the blade noises six blade exhaust fans operating at low speed are rapidly superseding the older four blade fans. A well designed fan of this type having 12-inch blades will deliver 1 000 cubic feet of air per minute when running at a speed of approximately 1 000 r.p.m., and a 16-inch fan, 1 800 cubic feet. The power required to operate such fans is very small, the 12-inch fans requiring but 36 watts and the 16-inch fans but 90 watts. Minimum attention is required, since oiling once a season is usually sufficient.

It is sometimes desired to mount the exhaust fans in the flues of hoods conveying fumes, smoke and the like from stoves, etc. This is never recommended as the solid matter in the air being drawn through the motor windings is deposited there and sooner or later results in a breakdown. In the case of direct-current motors, frequent attention would be required to keep the commutator in running condition. Even the supplying of totally enclosed motors does not render the fan satisfactory and a small motor-driven blower in which the air is not drawn through the motor should be used. The installing of exhaust fans in the upper half of the windows or in transoms is most effective for kitchens and lavatories and places of like character and excellent results have been obtained from installations of this type.

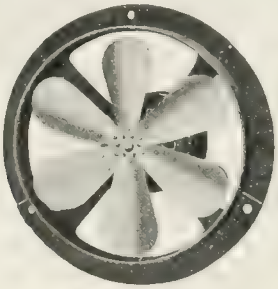


FIG. 2—A SIX-BLADE WESTINGHOUSE EXHAUST FAN

AGITATOR FANS

It is not generally known that beside the cooling effects of agitator fans, the physical discomfort ex-

FIG. 3—A CONVENIENT AND APPROPRIATE LOCATION FOR A LIVING ROOM FAN

perienced in breathing partly vitiated air can be eliminated and no ill effects felt from breathing it if the air is stirred up by agitator fans. The belief that vitiated air acts directly on the lungs has been disproved by Dr. Leonard Hill, of London, who has shown that the effect is transmitted through the skin. Keeping this in mind it is readily understood why the turning on of an agitator fan in a stuffy room gives instant relief without perhaps creating any actual ventilation. Many types of agitator fans have made their way into the market, each being a modification of previous types and arranged for the particular application for which it is intended. The variations in design are mostly made with reference to the method of mounting. Thus we have ceiling, counter and floor column fans; ordinary desk and bracket fans; telephone booth, railway coach, Pullman berth and limousine fans. Upright and bracket mounted fans are made in stationary and oscillating types. The oscillating

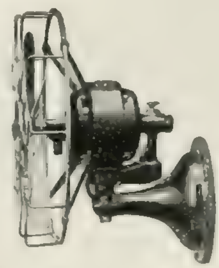


FIG. 4—AN AGITATOR FAN OF THE OSCILLATING TYPE

fan is a great improvement on the stationary fan since it distributes a breeze over a large area by swinging from side to side and can be used in many places where a fan giving a steady breeze in one direction might be objectionable. Persons in the immediate vicinity of a fan sometimes object to a fan blowing on them continuously but are not disturbed by an occasional breeze.

FIG. 5—AN EFFECTIVE LOCATION FOR AN OSCILLATING FAN

If it were not for electric fans, most of our nickelodeons and small theatres would be compelled to close their doors as soon as warm weather arrives. By means of agitator fans places of this kind are usually well equipped to keep their patrons cool and comfortable. In locating fans in nickelodeons they should be placed along the side walls 25 feet apart and just high enough not to be touched by persons walking beneath them. With an auditorium 25 feet wide or less, 12-inch fans will suffice and the 16-inch fans for auditoriums in excess of this width. The angle of inclination of the fan should be such that a line through the shaft center would fall three feet short of the center of the auditorium. If the fans are stationary, they should be directed slightly in the direction of the fans exhausting the vitiated air. Oscillating fans, however, give more satisfactory results.

In theatres having balconies 30 to 35 inch ceiling fans should be mounted beneath them and spaced 20 to 25 feet apart each way. If the balconies are sufficiently high to permit, 50 to 60 inch fans can be utilized and hung 30 to 40 feet apart each way. Care should be taken in hanging ceiling fans under balconies to see that they do not interfere with the line of vision from the highest seats in the rear.

In restaurants, stores, offices and places of like character, the arrangement of the interior will, in most cases, determine whether the desk, bracket ceiling, counter or floor column fans should be used. For interiors not more than 25 feet in width, 12-inch fans should be placed along the walls every 25 feet. Interiors in excess of this width will require 16-inch fans. If either 12 or 16 inch oscillating fans are used they can be spaced 30 feet apart along the walls and with more efficient results. There are many interiors, especially in stores where the wall space is taken up by shelves, etc., and if no columns are available for mounting bracket fans, it will be necessary to use either ceiling, floor, or counter column fans. When used for interiors 25 feet wide or less ceiling fans should be from 30 to 35 inches in diameter and placed 25 feet apart on a line through the center of the store. For larger interiors two rows of 30 to 35 inch fans, or one row of 50 to 60 inch fans should be used. The small fans should be placed 20 to 25 feet apart each way through the center of the store and give a better distribution than the larger fans which, if used, should be placed 30 to 35 feet apart each way in a similar manner.

Counter and floor column fans are used where ceilings are too high for mounting ceiling fans or where they would be objectionable on account of the appearance or construction of the ceiling. Fans of either the counter or floor column type are mounted along the counters one every 30 or 40 feet. Floor column fans may be mounted 30 to 40 feet each way in such places as depots, restaurants and lobbies, with very satisfactory results.

The extreme ease of portability of desk and bracket fan makes it possible with but one fan in the home to adopt it to many uses. Six blade or residence fans are especially adapted to home use. As the blades do not move so fast, they make less noise than four blade fans and still blow as much air with the same power consumption. A well-designed residence fan with a 12-inch diameter blade is very economical in the current it consumes and will run two and one-half hours on a cent's worth of current. The smaller eight-inch, four-blade fan will run five hours for one cent and the breeze it will give is quite astonishing. One of these eight-inch fans placed upon an open window sill at night directed inward will keep a fair

[illegible]

sized bed room cool and comfortable. A large room would, however, require a 12-inch fan. In using fans in the bed room, a small eight-inch fan placed near a baby's crib will aid most effectively in promoting restful slumber, but care should be exercised not to have the fan blowing directly on the child. The same care should be taken in the case of older persons as a strong current of air so directed might result in developing slight colds.

Mealtime on warm days is something very trying as it is generally not possible to secure natural circulation or make provision for dining outdoors. At this time, a 12-inch fan, either stationary or oscillating, will be greatly appreciated and can be mounted on an open window sill blowing inward so as to aid any natural circulation, or placed upon a mantel, or mounted as a bracket fan on a nearby wall. A similar arrangement can be used for a library or living room with most gratifying results.

The home kitchen should be carefully ventilated, especially in the warm weather, and a most effective

FIG. 7—RESTAURANT EQUIPPED WITH WESTINGHOUSE FLOOR COLUMN FANS

method to insure the removing of heated air is to swing the transom of an outside door from the top and in the "V" shaped opening formed at the end mount an eight-inch fan to blow outward. If the fan is set slightly back, the transom can be opened or closed at any time without disturbing the position of the fan. This will serve to remove the heated air while a second eight-inch fan may be placed nearby on an open window sill and directed inward. With this arrangement, the summer meals can be prepared in comfort and coolness.

There are people who pack their fans away when Jack Frost comes, but the wise man, if he has a hot water heating system in his house, will place his fan on the floor close to the radiator and directed at it, thus securing better heat distribution. In one case, last winter, during one of the extremely cold days when the heating system was being taxed to the utmost and the family were huddled around in rather lukewarm groups, one of the boys remembered the faithful little fan which had helped to keep them cool the previous summer and wondered if it could not circulate some of the warm air from the radiator. He hastened to unearth the fan from its resting place and the exclamations of delight as the room warmed up indicated that another family had discovered that the

FIG. 8—A CONVENIENT LOCATION FOR AN OZONIZER IN A RESTAURANT

use of the fan motor does not cease with the close of summer.

In the case of homes having hot air heating systems, the cold air inlet pipe is generally extended to the exterior of the basement to insure a good circulation. On extremely cold days this results in overtaxing the furnace, a contingency which can be avoided

FIG. 9—OZONIZER EQUIPMENT IN AN OFFICE

by removing all the cold air pipe except one short section next to the furnace and setting a 12-inch fan in front of the open pipe. This gives a much better circulation and supplies the furnace with air that is already partly heated and increases the heating capacity without forcing the fire. As the air of most basements

is sufficiently clean to be circulated through the furnace, this procedure is to be recommended.

There are other numerous uses of fans, both in the shops and in the home, among which may be mentioned, driving flies from eatables in stores, preventing frost from forming on windows during the winter,

FIG. 10—AN INSTALLATION OF FAN AND OZONIZER IN A BANK VAULT

preventing printing press rollers from melting, keeping the air clean in crowded elevators, drying negatives and prints in the photograph gallery, specially mounted fans to keep "Central" cool, drying the hair after shampoo, ventilating telephone booths, etc.

OZONIZERS

The ozonizer occupies a very important place in connection with the improvement of air conditions. Ozonizers *do not* supplant ventilation, but are most valuable aids to it. The regular ventilation system, besides supplying fresh oxygen to replace that which is used up, must also provide for the removal of air laden with impurities. This latter function is that of the ozonizer which destroys the impurities instead of removing them. This, then, obviates the necessity of handling large quantities of air, tending to produce draughts and requiring elaborate ventilating apparatus. In cold weather this exchange of large volumes of air means an enormous waste of heat, since all the heat in the air removed is lost and the cold air coming in must be heated to the desired temperature. So it is that the ozonizer is a great conserver of energy, since with its use it is not necessary to burn tons of coal to heat large quantities of outdoor air which is merely taken into our buildings and passed out again to the winter's cold. As the cost of ozonizing is very small, it has been conclusively shown that a very large proportion of the expense of heating buildings, theatres, schools, etc., could be saved by judicious use of ozone in connection with the air circulating apparatus. In support of this, attention is called to the most exhaustive and conclusive tests* made at the Jackson School in Minneapolis, in February and [illegible], in which the air of a certain room was washed, ozonized and re-circulated continuously for a period of three hours and two hours each day for three weeks without admitting any outside air other than that ordinarily leaking through the cracks of windows and occasionally opened doors. Careful study of the pupils in this room was made daily and no deleterious effects observed when compared with a similar number of pupils in a room having ordinary ventilation.

TABLE II

Seating Capacity.	[illegible]
150	1
150-300	2
300-500	[illegible]
500-1 000	[illegible]
1 000-1 500	6
1 500-3 000	[illegible]

Ozonizers when used in theatres, halls or nickelodeons, should be specified according to Table II, which refers to ozonizers having a capacity of at least 300 milligrams of ozone per hour. They should be equally spaced around the walls, preferably near doors or windows, or they can be mounted on brackets near fan motors which will thus aid in diffusing the ozone. For home, office, or smaller enclosures, 75 milligrams per hour capacity is sufficient for each 400 square feet of floor space or about 4 000 cubic feet. The floor space generally determines the average number of occupants.

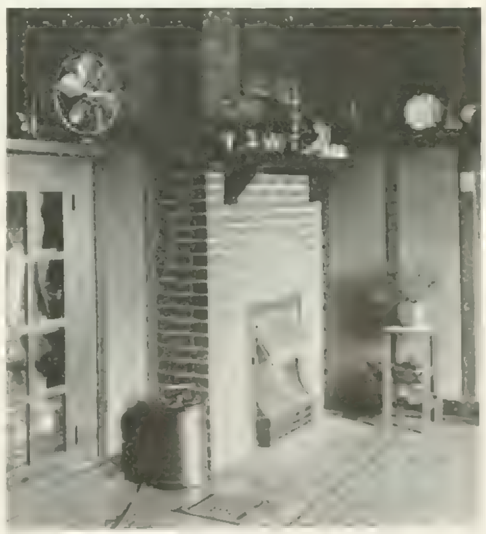


FIG. 11—THE FAN AND [illegible]

*A full report of these tests was read before the American Society of Heating and Ventilating Engineers at Buffalo on July 17th, 1913, by Frederic Bass.

The Electrically Heated Linotype Pot

H. M. Wicker

THE LINOTYPE MACHINE is one of the most wonderful inventions of modern times, yet few people outside the printing trade are at all familiar with it, and a large majority have probably never seen one. A short description of the machine will make it easier to understand the advantages of the electric type-metal pot.

This machine, as its name indicates, casts into one solid piece of metal, called a slug, a full line of type at one operation. The matrices, carrying the impressions of the characters to be used, together with the space bands, quads, etc., that make up these lines, fall into their various positions in the line in response to the operation of a keyboard similar to that of a typewriter.

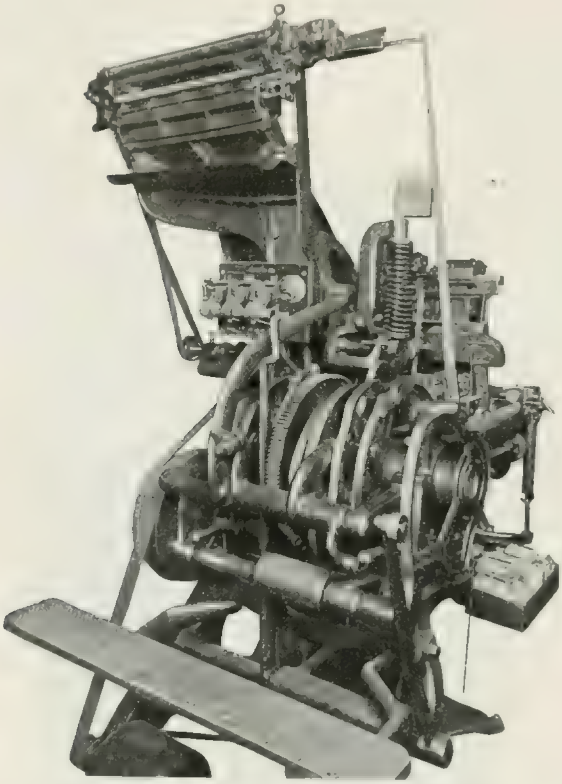


FIG. 1—REAR VIEW OF A LINOTYPE MACHINE
Equipped with electrically heated pot and control panel.

When the operator has filled the line, he presses a lever which automatically starts the machine and the line of matrices moves over to the point where it is to come into contact with the mould. The disc which carries the mould revolves, bringing the mould into position, the pot moves forward bringing the mouthpiece into close contact with the mould, the pot plunger descends in the crucible well and forces the metal into the mould where it immediately chills, forming the slug. The pot recedes, the distribution levers act to return the matrices to their places in the magazine and the space bands to their place, and the mould disc revolves to the ejecting position carrying the slug past a knife which trims it, the ejector blade pushes the slug out into the galley and the revolution of the machine in casting the slug representing one line of type is completed, the time required being about ten seconds. Meanwhile the operator is setting up another line and on again pressing the lever another line is cast. The maximum capacity of the machine is therefore about six lines per minute.

The average working temperature of the type metal in the pot is 550 degrees F. The melting pot may be considered as the heart of the machine, as the success or failure of any individual machine always hinges on the operation of its pot. Up to a very recent date, gas has been used almost exclusively for heating these pots where a gas supply was available and in places where no gas was to be had, gasoline or kerosene had to be used. The use of these heating methods has always been attended with so many difficulties that the melting pot, besides being the vital point, has been the weakest point in the machine. The quality of gas varies largely in different localities and the pressure in the supply pipes also varies at

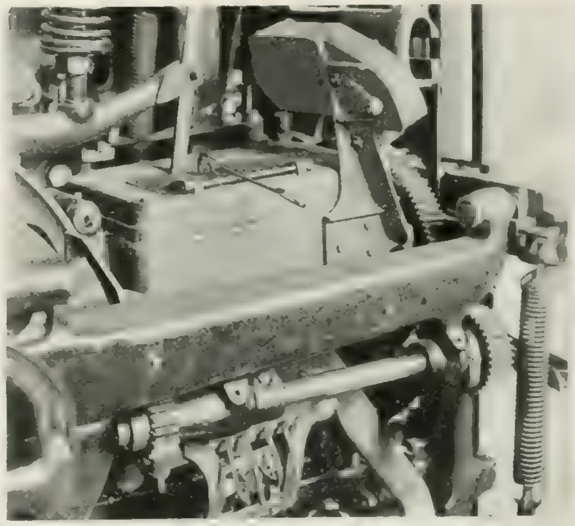


FIG. 2—DETAIL VIEW OF LINOTYPE POT INSTALLED

different times of the day. This has made the heat control very difficult and it has also been practically impossible to get a proper distribution of the heat as applied to the pot. The sanitary conditions, due to gas fumes, have been very bad. The use of electricity as a means of heating makes it possible to control the heat while perfect distribution is maintained, which insures the correct proportion of heat between the

main body of the pot and the mouthpiece or point of moulding at all times, which is essential to the production of perfect work.

The heat control is effected by an automatic magnetic switch operated by a thermostat, adjustable to any temperature, placed near the mouthpiece of the pot. The thermostat consists of an expansion rod,

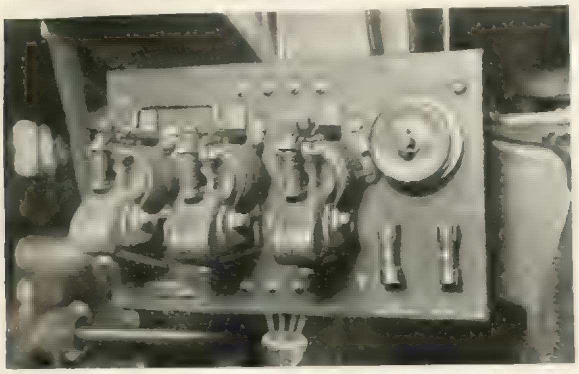


FIG. 3—CONTROL PANEL AS IN OPERATION

eight inches long, running parallel to the mouthpiece and operating a compound lever which opens and closes the parallel and series circuits on the switchboard, alternately.

When the pot is heating, two circuits of heating coils are used connected in parallel. When the correct working temperature has been reached, the thermostat acts on the automatic switch which throws these circuits into series, thus reducing the heat production to an amount which will maintain the working temperature without losing the heat distribution, as heat is still being supplied to all parts of the pot, and no exterior resistance is introduced into the circuit to reduce the efficiency by causing an exterior loss of heat.

One of these circuits is used exclusively to heat the mouthpiece and the throat leading up to it. The

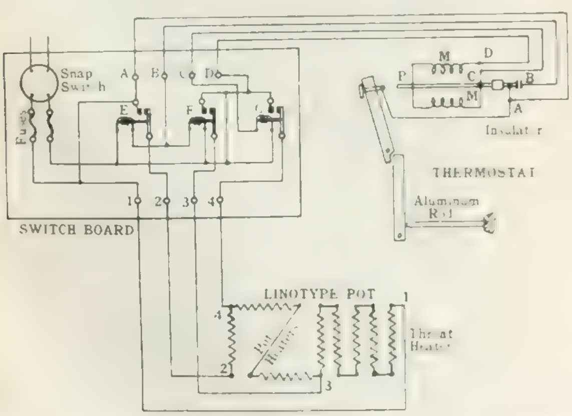


FIG. 4—COMPLETE DIAGRAM OF CONNECTIONS FOR HEATING OF LINOTYPE POT

mouthpiece is necessarily an exposed radiating surface and in addition to the loss from radiation it comes in contact with the cooler surface of the mould every time a slug is cast which is on an average of six times per minute. All of the heat thus taken away has to be replaced or the mouthpiece will get cold and chill the metal before it has time to entirely fill the mould, resulting in an imperfect face on the type. This heat must also be maintained at the mouthpiece without getting the metal in the pot too hot. If the metal is too hot both the mouthpiece and the mould soon get too hot and the metal will not chill in the mould quickly enough to make a solid slug, part of the metal flowing back into the pot, causing a porous slug, which is too weak to stand the heavy pressure of the stereotype press. When these slugs break down under this pressure very imperfect printing results, but the imperfection is usually not noticeable till the paper has gone to press; it may be serious enough to delay or cause the entire loss of the edition.

It is here that electric heat meets the requirements so effectually as to overcome all the troubles due to this cause. The coils are wound so that the exact amount of current is used in every part of the pot to maintain the right temperature at each point, whether

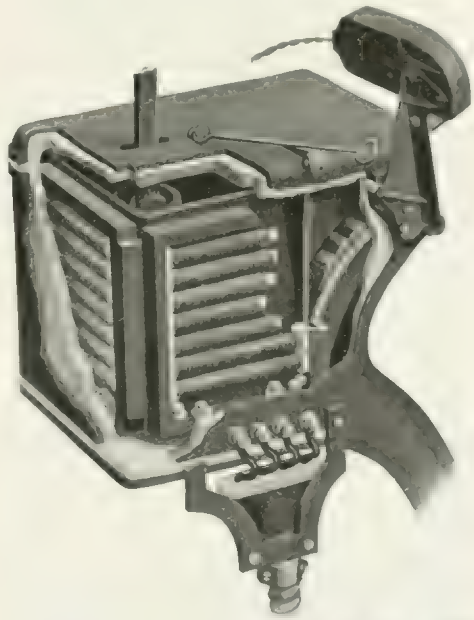


FIG. 5—VIEW SHOWING CONSTRUCTION AND THE INTERIOR ARRANGEMENT OF WESTINGHOUSE HEATING ELEMENT

the maximum or minimum amount of current is being used. This proportion is so nicely adjusted that it makes no difference whether the machine is working fast or slow, or is not being used at all, or whether large or small slugs are being cast. A slightly lower temperature of the metal is necessary in casting big slugs for the reason that a greater mass of metal has to be cooled by the mould during the few seconds that it is in contact with the mouthpiece, and vice versa, a small slug will cool quickly and if the temperature of the metal is a little low it will cool too quickly, causing an imperfect face. When the machine is casting big slugs both the mouthpiece and the mould heat up and by having the thermostat near the point of moulding this excessive heat acts directly to cut down the general heat production, so that all changes in measure, size of slugs, etc., are automatically taken care of by the thermostat. This is especially important in

offices where frequent and radical changes are made in the classes of work done on one machine. Some of the later models of the linotype carry as many as eight faces of type at the immediate command of the operator, and all changes in measure and sizes of slugs are quickly made by the operator without leaving his seat. The fine adjustment and heat distribution effected by the use of electric heat, makes it the ideal heating method for the rapid and perfect production of the greatest variety of fine linotype work.

The sanitary conditions are greatly improved by the use of electric heat, as there are no fumes and very little heat escapes to overheat the room, as the heat is all sealed in and no draught is necessary as in the use of combustion of any kind. Heat by combustion is also seriously affected by currents of fresh air, as from a window, which are so necessary for the health and comfort of the operator. Electrically heated pots are not affected by air currents and the amount of ventilation is therefore not limited.

High Voltage Distributing Transformers

E. G. Reed

The relative importance of the higher voltage distributing transformers seems to be increasing. That is, at the present time there is a more rapid increase in the number of transformers which deliver current directly to the consumer from 4 400 to 33 000 volt lines, than in the voltages below

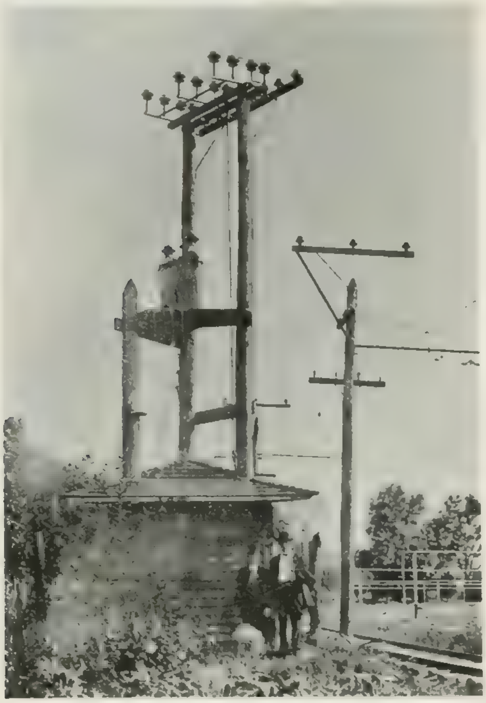


Fig. 1—One method of installing a high voltage distributing transformer.

4 400 volts. This does not mean that the actual number of the higher voltage transformers installed is greater than those of lower voltage. In general, the transformers under discussion range in voltage from 4 400 to 33 000 volts.

Such transformers are usually mounted on a pole or platform as close as possible to the consumer; Fig. 1 shows one of the many methods of installing such a transformer. This particular installation was on a farm through which passed a 22 000 volt transmission line. The use of the outdoor type of transformer permits the tapping of such a transmission line to take off a relatively small amount of power at a reasonable cost. The installation consists of a 15 k.v.a. outdoor type transformer, giving 110 or 220 volts on the secondary. The small building contains the switchboard, a watthour meter for measuring the energy received, and the auto-starter for a ten horse-power motor which is located about 1 200 feet away on the river bank. The motor is used for pumping water into a tank located just back of the house. When desired, it can also be used for irrigating the truck farm; an operation accomplished by means of several valves which can be opened and the water allowed to flow by gravity through some piping which is perforated at intervals, thus spraying the water over the land. In this particular case, advantage was taken of the electrical installation to light the residence and equip it with many modern electric devices.

Fig. 2—General appearance of a medium size 11 000 volt Westinghouse transformer

The general appearance of transformers of this type is shown in Figs. 2 to 5. The general construction used is core type with the concentric type of winding. The present design of the magnetic circuit is the result of careful study to eliminate all possible

elements tending to increase the iron loss or exciting current. The construction is of L-plates, as shown in Fig. 6, which gives but two joints in the complete circuit; also the magnetic circuit is widened outside of the coil so that the magnetic density at the joints is lower than at other parts of the circuit.

Inasmuch as transformers for this class of service transform high voltage current to a low voltage and deliver it directly to the consumer, the insulation must

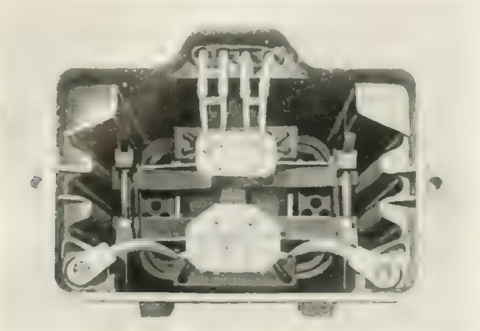


FIG. 3—VIEW LOOKING INTO TOP OF TRANSFORMER SHOWN IN FIG. 1

be of. the highest grade. While the low tension circuits should be grounded, it is often very difficult to secure effective ground connections, particularly during periods of hot dry weather.

The insulation between the turns consists of the actual insulation on the wires themselves. The smaller

FIG. 4—A SMALL 11 000 VOLT TRANSFORMER REMOVED FROM CASE

sizes of wire are covered with a layer of enamel and then a single cotton covering. On the line end of transformers of medium voltage, double cotton covered enamel wire is used, while on the higher voltage transformers the end turns are further separated by string as shown in the top coil of Fig. 7. The layers are separated from each other by a layer or layers of high grade paper, the turns on the ends of the coils being prevented from getting out of the layers by a crimp or fold in the insulation. In order to keep the voltage between layers to a low value, the high tension

FIG. 5—A 100 K.V.A., 6600 TO 220 VOLT TRANSFORMER REMOVED FROM CASE

winding is separated into a number of coils. The vacuum drying and impregnating filling treatment is of particular value in transformers of this class because of the relatively large number of turns of fine wire used.

The insulation between the high and low tension windings should be a continuous insulating tube of

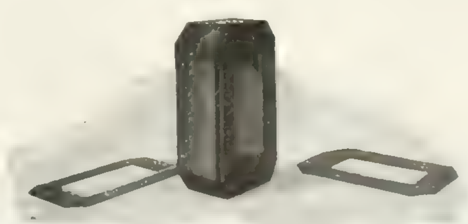


FIG. 6—MAGNETIC CIRCUIT OF TRANSFORMER
Showing position of joints and widening of iron external to coils.

high dielectric strength, which will take up a relatively small amount of space and which will maintain its dielectric strength after long periods at fairly high temperatures. Tubes which are almost ideal for these conditions are shown in Fig. 9. These tubes are made with a high grade of mica and imported Swedish paper, on machines specially constructed for this purpose. This insulating material is called micarta—meaning better than mica. The paper reinforcing the mica imparts to the finished tube the mechanical characteristics which the plain mica lacks. The paper,

which has been previously covered by a bond of shellac or bakelite, as the conditions may demand, is wound between steel rolls, under heat and pressure, on a steel mandrel. The bond is melted by the heat

FIG. 7—AN 11 000 VOLT HIGH TENSION WINDING
Showing sub-division into coils and string insulation between end turns.

and the pressure between the rolls compresses the paper very solidly together. Built-up mica sheets are fed between the paper as it is wound on the mandrel, so that approximately 50 percent of the solid finished

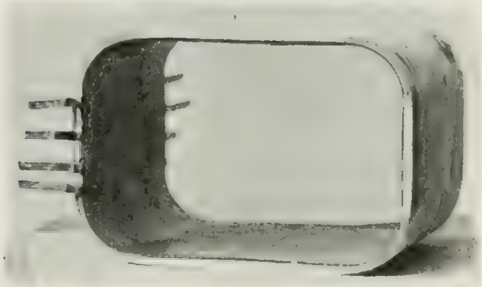


FIG. 8—METHOD OF WINDING HIGH TENSION COIL ON INSULATING BARRIER BEFORE ASSEMBLING WITH THE LOW TENSION COIL AND THE CORE

tube is pure mica. In other words, 25 percent of the total finished thickness of the tube is wound on the mandrel as paper, then 50 percent of the thickness is fed in as mica and the remaining 25 percent of paper

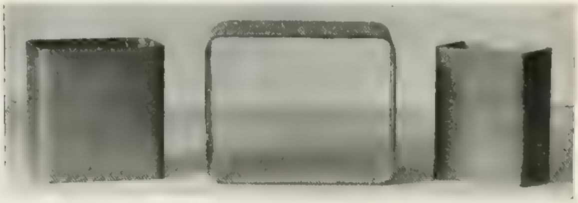


FIG. 9—MACHINE FORMED INSULATING BARRIERS SUCH AS USED IN FIG. 8

goes on the outside. By this method of manufacture, a tube of maximum dielectric strength is provided for a given thickness. The tube is absolutely solid and of such a character that it will ring like metal when struck a sharp blow. The mica goes into the tube without wrinkles, which makes a uniform tube without flaws. For those coils which are wound directly on the tube, the paper part of the barrier on each part of the mica protects the mica from mechanical stresses. This method of making these important barriers is a great improvement over the former method of winding the mica sheets between the coils by hand. This was accomplished by wrapping by

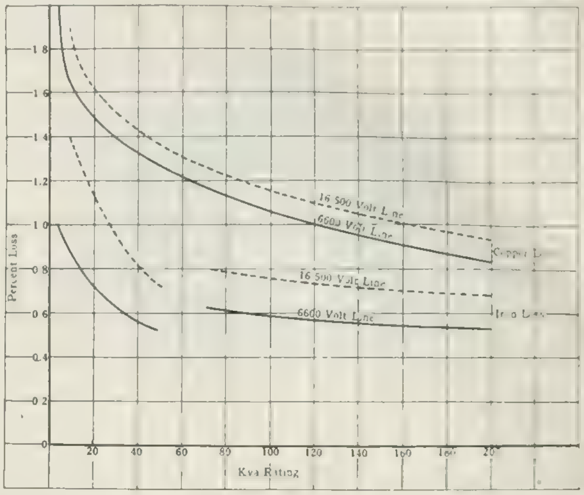


FIG. 10—VARIATION OF PERCENT COPPER LOSS WITH DIFFERENT SIZES OF DISTRIBUTING TRANSFORMER

hand the sheets of mica on top of one winding when it was on the mould and then winding another coil directly on the mica sheets. It is impossible to wind the mica sheets by hand and prevent wrinkles. When a coil is wound over these wrinkles there is great like-

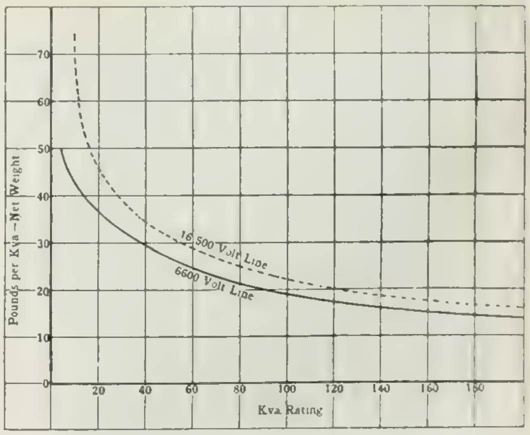


FIG. 11—VARIATION OF NET WEIGHT IN POUNDS WITH DIFFERENT SIZES OF DISTRIBUTING TRANSFORMERS

lihood of the mica in the barrier being broken through at these points.

An idea of the performance characteristics of these transformers may be secured from the curves in Fig. 10 which give the percentage of iron and copper loss for sizes up to 200 k.v.a. for the 6 600 and 16 500 volt classes. Fig. 11 gives the pounds weight per kilovolt-ampere for the same range of sizes.

The Efficiency of the Incandescent Lamp and its Commercial Application

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THE efficiency of an incandescent lamp may be considered from two points of view, first, the true efficiency; and second, the relative or commercial efficiency. By the true efficiency we designate the ratio of the energy put into the incandescent lamp to the energy obtained therefrom in the form of light. This ratio in the best vacuum incandescent lamp probably does not exceed four or five percent, whereas in the most recent type of incandescent lamp, which is filled with an inert gas, it rises to eight or nine percent. The reason for this low efficiency is that only a comparatively small amount of the radiation emitted by the incandescent filament is visible, the greater part of the energy being converted into radiation below the visible range of the spectrum, while only a minute part of the radiation is above the visible portion of the spectrum.

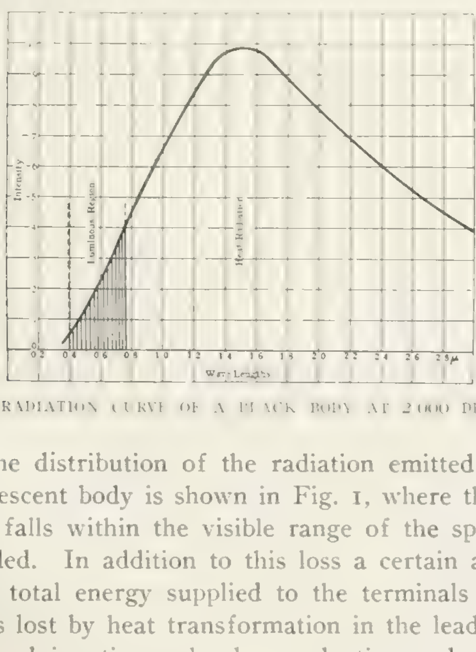

FIG. 1—RADIATION CURVE OF A BLACK BODY AT 2000 DEGREES C

The distribution of the radiation emitted by an incandescent body is shown in Fig. 1, where the part which falls within the visible range of the spectrum is shaded. In addition to this loss a certain amount of the total energy supplied to the terminals of the lamp is lost by heat transformation in the leading-in-wires and junctions, also by conduction and convection in the gases present in the lamp and the cooling effect of anchors and other supports. These losses in a modern incandescent vacuum lamp are so small that they are practically negligible. This statement is not entirely true of the most recent types of gas filled lamps, but whatever losses occur are kept within the narrowest possible limits by suitable arrangement of the incandescent body and the choice of a suitable gaseous medium, which is a poor conductor of heat. It is thus quite true that as a means of translating electrical energy into light, the incandescent lamp must be considered somewhat inefficient as compared with other electrical translating devices, such as generators, motors, transformers, etc.

The relative or commercial efficiency of an incandescent lamp is the ratio of the energy input in watts to the amount of light obtained from the lamp measured in terms of candle-power. The factor thus obtained is called the rating of incandescent lamps, and gives the number of watts consumed per candle-power obtained. The commercial efficiency of an incandescent lamp has shown an improvement of considerable magnitude within the last few years, and especially since the advent of the metal filament lamp.

The enormous progress made in the art of manufacturing incandescent lamps can best be realized when it is recalled that, in the early days of lamp manufacture, a carbon filament lamp required 7 to 10 watts per candle-power, whereas in the most recent type of gas filled metallic filament lamp the energy consumed is but 0.5 watt per candle-power.

Owing to improvements in the manufacture of the carbon filament and in the manufacturing process of the lamps, it was possible towards the end of 1896 to make carbon lamps requiring a consumption of 3.1 watts per candle-power. The invention of the so-called metallized filament lamp (the filament of which is simply an ordinary carbon filament, but which has been heated during its process of manufacture to a very high temperature in the electric furnace), made it possible to reduce the watt consumption to 2.5 watts per candle-power. About the same time (1905-06) lamps with metallic filaments began to make their appearance, the first of these being the osmium lamp, the filament of which was composed of metallic osmium. This lamp was operated at an efficiency of approximately 1.9 watts per candle-power. This lamp was followed by a lamp with a filament composed of a drawn wire of metallic tantalum which had an efficiency of approximately 1.9 to 2 watts per candle-power.

During the latter part of 1906 the tungsten lamp, which had a filament composed of tungsten squirted from a metallic tungsten paste, appeared in the market. The efficiency of this first type of tungsten lamp was in the neighborhood of about 1.5 watts per candle-power. Later improvements in the manufacture of the filament and in the manufacturing process of the lamp, especially after the introduction of the drawn wire tungsten filament, made it possible to lower the watt consumption to one watt per candle-power. By taking advantage of burning that filament under suitable conditions in a lamp filled with an inert gas, this watt consumption has recently been reduced to 0.5 watt per candle-power. The above statements are shown in condensed form in Table I, which gives the

dates that the principal types of incandescent lamps appeared on the market, the watt consumption per candle-power, and the reversed ratio of candle-power per watt.

It is of interest in this connection to inquire into the reasons by virtue of which the improved efficiency of these various types of lamps has been brought about. The principal factors, however, are first, the temperature at which the various types of lamps operate, and, second, the character of the luminous radiation obtained from them. The temperature at which a material can be operated continuously in a vacuum, as is the case with the incandescent lamp, depends on its melting point and on the rate of its evaporation or disintegration at the various operating temperatures. The approximate melting point and the temperature of operation of the various lamp filament materials mentioned above is given in Table II. From this table it appears that the temperature at which the least efficient lamp, namely, the ordinary carbon lamp, is operated, is about 50 percent lower than its melting point. This temperature, however, is about the maximum which could be used commercially on account of the rapid evaporation or disintegration of the carbon filament material. This is due to a great extent to the fact that the carbon filament as ordinarily manufactured, is not an absolutely solid body but simply a comparatively loose aggregation of particles of carbon which, at higher temperatures than the ordinary operating temperature of the lamp have a strong tendency to disintegrate mechanically. This disintegration, of course, is accompanied by a disposition of the material evaporated from the filament upon the coolest part of the lamp, namely the bulb, and a consequent blackening of the bulb and absorption of light. Owing to the peculiar change which the carbon filament undergoes by heat treatment, it is possible to increase the operating temperature of the metallized filament to a certain extent and still prevent its rapid disintegration.

TABLE I

Date	Watts per candle	Candles per watt	Type
1879	7.0	0.14	Carbon
1886	4.0	0.25	Carbon
1896	3.1	0.31	Carbon
1905	2.5	0.4	Metallized
1906	2.0	0.5	Tantalum
1907	1.25	0.8	Mazda
1913	1.0	1.0	Mazda (Drawn Wire)
1914	0.5	2.0	Mazda (Inert Gas)

TABLE II

Filament Material	Melting Point	Normal Operating Temperature
Carbon	3750 Degrees C.	1800 Degrees C.
Tantalum	3100 Degrees C.	2000 Degrees C.
Tungsten (in vacuum)	3200 Degrees C.	2300 Degrees C.
Osmium	2500 Degrees C.	1900 Degrees C.
Tungsten (inert gas)	3200 Degrees C.	2700 Degrees C.

The next problem to be attacked in the manufacture of incandescent lamps was that of obtaining bodies which could be operated at a higher temperature, and as a natural consequence the choice fell on the metals which have a very high melting point. A number of metals were tried in this connection, beginning with osmium and tantalum and ending with tungsten, that being the element which has the highest melting point of all metals known at the present time. In addition, these metals can be operated in a vacuum at temperatures quite close to their melting points without any prohibitive amount of evaporation taking place. A further means of increasing the efficiency of the tungsten lamp was given by the possibility of introducing small amounts of chemical substances into the lamp, the presence of which had the effect of combining with the material evaporated from the filament rendering it innocuous as far as the light of the lamp is concerned. These chemicals give off gases which unite with the material evaporated from the filament converting it into compounds of light color which, even if they deposit on the bulb, cannot be easily seen and, therefore, do not appreciably impair the luminosity of the lamp. In addition, they probably exert some slight pressure upon the filament which still further decreases the tendency of the filament to evaporate.

TABLE III

Absolute Temperature	Luminosity Factor
900 deg.	30
1000 deg.	25
1100 deg.	21
1200 deg.	19
1400 deg.	18
1600 deg.	15
1900 deg.	14
2100 deg.	12

It is a well known fact that the pressure of the surrounding medium has a considerable effect upon the tendency of a material to evaporate; thus, for instance, water boils at sea level at 212 F. under ordinary atmospheric pressure existing at sea level. That same water when carried up to the top of Pikes Peak will boil at about 190 degrees F. This difference in the boiling point is simply due to the lower barometric pressure existing in that altitude. What is true of water in this instance is also true of other materials, such as tungsten. Advantage was taken of this fact to burn a tungsten filament at a temperature nearer its melting point than could be obtained in the ordinary vacuum incandescent lamps without excess of disintegration. The problem was solved by the introduction of an inert gas into the lamp bulb which exerted a pressure upon the filament and thus materially decreased its tendency to evaporate. It is thus possible to burn such lamps at approximately 2 700 degrees C., which temperature is quite close to the melting point of tungsten. With this increase in temperature (so close to its melting point) it seems that the development of a lamp with a tungsten filament has about reached its maximum. Whether the

future development of the incandescent lamp will show a reversal to the carbon filament, the melting point of which, as shown in Table II, is considerably higher than that of tungsten, is a question of the future. If suitable means can be found to obtain a carbon filament of the same close structure as the present drawn wire tungsten filament and to suitably counteract its tendency to evaporation, there is no question that such a lamp would be considerably more efficient than the latest improved types of lamps with tungsten filaments operated in an atmosphere of inert gas.

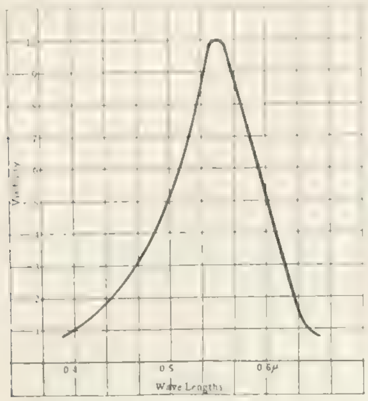

FIG. 2—SENSIBILITY CURVE

Showing luminosity at various wave lengths for the same energy distribution.

The ultimate goal of the solution of the problem of converting electrical energy into luminous energy would be of course a so-called cold light, and it seems that the future development will be in the direction of the use of incandescent gases rather than by a reversal to the carbon filament. An illustration of the increase of luminosity with temperature is furnished by the data in Table III, which illustrates the increase of luminosity at various temperatures with a platinum filament. This table shows that for a slight increase of temperature a relatively large gain in luminosity is secured. This table also shows that at lower operating temperatures the increase of luminosity with temperature changes is considerably larger than at temperatures in the neighborhood of 2 100 degrees absolute. At this point the luminosity factor reaches 12, which is about the minimum value. The luminosity factor for higher operating temperatures than given in the table can be considered to be only slightly less than 12, for at this point the luminosity factor is reported to be nearly constant.

A second factor contributing to the improved efficiency of the more recent types of incandescent lamps is the so-called selectivity of the radiation. Selective radiation (for the purpose of this discussion) may be considered to be the ability which some materials have of radiating relatively larger proportions of their energy within the visible spectrum than the theoretical black body. Such materials will, therefore, produce more light for a given amount of energy. The selectivity is still further increased if the radiating body has the property of giving out a comparatively large proportion of its radiations within the middle part of the spectrum. This physiological phenomenon is due to the fact that the human eye is more sensitive to the yellow and green rays which appear within this portion of the spectrum. Fig. 2 shows that energy radiations of wave lengths in the neighborhood of 0.7 μ and 0.4 μ produce relatively very little light while energy radiations of wave lengths of 0.5 μ and 0.6 μ produce illumination effects which are relatively large. Thus it can be seen that if the distribution of energy of a light source is such that a relatively large portion falls within wave lengths of 0.5 μ to 0.6 μ a very considerable advantage is secured from the standpoint of luminous efficiency. The color, however, being in the green and yellow, may be disagreeable.

The influence of selective radiation on the efficiency of an incandescent lamp appears to be best shown in the case of the osmium lamp which operates at a comparatively low temperature of 1 900 degrees C., and yet has a greater efficiency than the tantalum lamp operating at a higher temperature. This phenomenon appears to be only explainable by the presence of selective radiation in the osmium filament.

Fig. 3 shows energy and luminosity curves for carbon and tungsten filament lamps, and graphically illustrates the advantages which the tungsten filament has in its energy distribution as compared with the carbon filament. The figure does not include the energy radiation from the new types of tungsten lamps filled with inert gases, but there is no doubt that the radiations will show a considerable increase in effective luminosity over the ordinary tungsten lamp.

In conclusion, it remains to be said that not only has the efficiency of lamps been increased but also that the color of the light furnished has been steadily improved and brought nearer to daylight until, in the tungsten lamp filled with inert gas, it approximates very closely to the color of average daylight. Thus

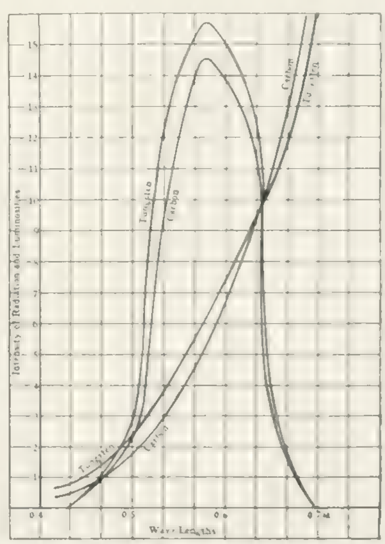

FIG. 3—RELATIVE CURVES OF LUMINOSITY AND INTENSITY OF RADIATION FOR CARBON AND TUNGSTEN

The inverted V-shaped curves are the luminosity curves, indicating the wave length limits between which a radiating body is luminous. The remaining two curves indicate the rapidity with which the intensity of radiation or heat dissipation increases with the wave length.

as shown graphically in Fig. 4,* the color of the carbon filament lamp is furthest removed from daylight and there is a gradual approach to daylight successively through the metallized lamp and the old type of tungsten lamp, which approaches daylight quite closely. It can be shown that by the use of the necessary color absorbing materials, as in conjunction with properly designed enclosing devices, a color which is equivalent to daylight can be obtained with a loss of not more than 60 percent of the luminosity of the lamp. A gas filled Mazda lamp, therefore, which is rated at 0.6 watts per candle gives the equivalent of daylight at approximately two watts per candle. This fact demonstrates that we can now produce daylight more efficiently and with less expenditure of electrical energy than was required for running the

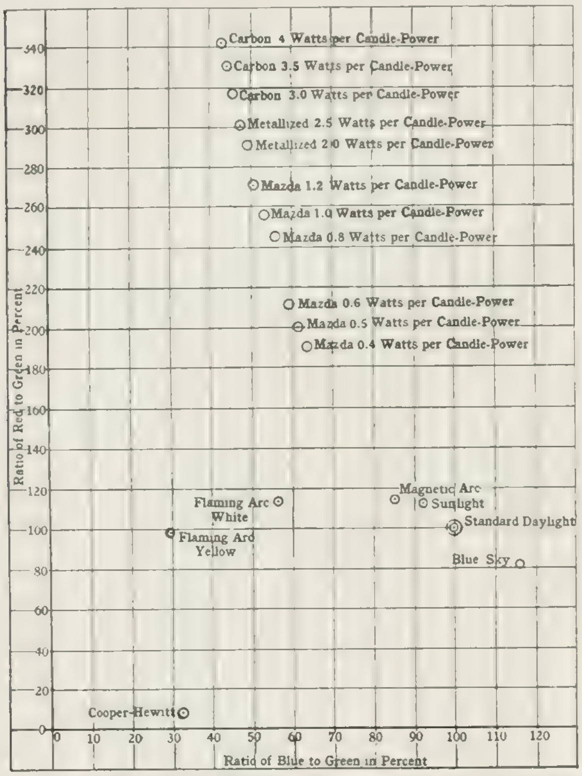

FIG. 4—CHART GIVING RELATIVE AMOUNTS OF RED, BLUE AND GREEN IN THE VARIOUS TYPES OF ILLUMINANTS

unsatisfactory carbon lamps a few years ago. The energy radiation within the luminous spectrum of the new high candle-power Mazda lamp as compared to the ordinary vacuum lamp, is shown in Fig. 5, which indicates graphically the greatly increased proportion of green and blue rays and the lesser amount of red rays which account for its whiter light.

The enormous progress made in the manufacture of incandescent lamps, and especially within recent years, has made it possible to increase their range of usefulness beyond anything possible with the carbon lamp. A graphical illustration of the gradual extension of the range of candle-power of incandescent lamps available for commercial purposes is shown in Fig. 6. This shows that lamps are now made of candle-powers which permit them to compete with other illuminants in a great many fields into which they could not enter formerly. Thus, for instance, the range of ordinary Mazda lamps reaches from the minute can-

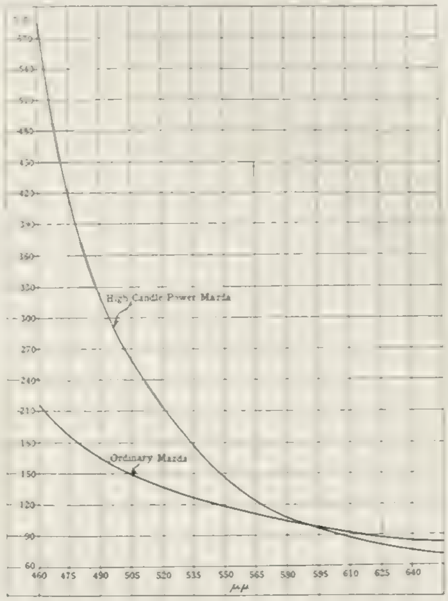

FIG. 5—SPECTRAL COMPARISON OF LIGHT. HIGH CANDLE-POWER MAZDA VERSUS ORDINARY MAZDA

dle-power lamp required for flashlights to 400 and 500 candle-power which are used as substitutes for arc lamps. Mazda lamps are now made rugged enough for any kind of service even in locations where they have to stand a considerable amount of rough handling, such as in automobile and in train service. They are adapted to all kinds of residential, department store and industrial lighting service. With the improvement of the quality and the life, due to the introduction of the chemical substances above referred to and to improvements in construction which have been introduced, a stage of perfection has now been

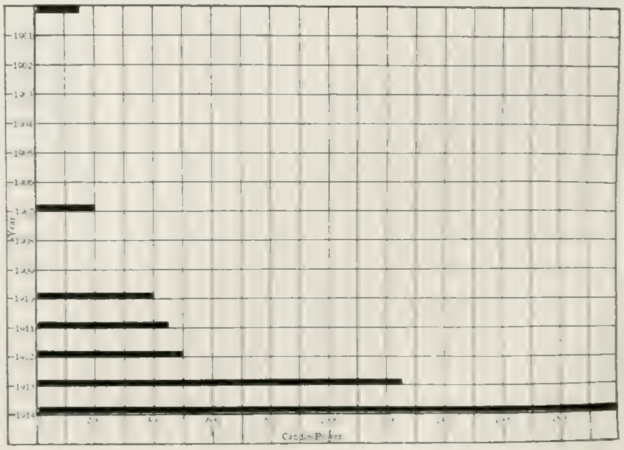

FIG. 6—CHART SHOWING STEPS IN CANDLE POWER RANGE OF INCANDESCENT LAMPS

reached which was never dreamt of in the days of the old carbon lamp. The incandescent lamp of the present day has an enormous range of adaptability to all kinds of voltages from 0.5 to 260 volts. It can be used on all kinds of frequencies, even as low as 25

*Taken from an article by a German investigator, Dr. L. Bloch, in the *Elektrotechnische Zeitschrift for* Nov. 13, 1913, p. 1300, who has made a long series of comparative experiments with regard to the color value of various illuminants.

cycles, and, with the possible exception of the new types of gas filled lamps, is adapted to all kinds of conditions of temperature and environment.

In addition, the ductile tungsten filament has made it possible to develop a series of types in which the filament is concentrated in the smallest possible space, in order to come as close as possible to the theoretical point source of light. This has made it possible to develop a series of automobile and locomotive headlight lamps which have proven of very great value in commercial service. The introduction of the 0.5 watt per candle gas filled Mazda lamp furnishes a further possibility of extending the field of usefulness of the incandescent lamp, especially in the region of high candle-powers. This development has extended the range of the Mazda lamp for street lighting from the suburban into the business districts of cities so that they can now compete with every source of illumination. The concentrated form of filament in conjunction with the atmosphere of inert gases has made it possible to develop powerful types of locomotive headlights and lamps for projection apparatus and other applications where the concentrated light source was an absolute necessity, and where formerly the arc lamp had an undisputed field.

Energy Required for Heating Buildings

W. O. Peale

IT IS frequently necessary for central station solicitors and consulting engineers to furnish an estimate of the electrical energy required to heat a given room or building, and to make comparisons between this and other methods of heating. To those who may not have data at hand on this subject the present article should be of value. The relative heat values of various fuels are indicated in Table I, assuming 100 percent efficiency of heat application.

TABLE I—RELATIVE HEAT VALUES OF VARIOUS FUELS.

Material.	Units Burned.	B.t.u.	Kw-hr.
Coal—Anthracite....	2 000 lbs.	27 000 000	8 000
Coal—Bituminous...	2 000 lbs.	29 000 000	8 500
Gas—Natural.......	1 000 cu. ft.	900 000	265
Gas—Artificial......	1 000 cu. ft.	600 000	175
Wood—Hickory....	Cord—4 500 lbs.	16 500 000	4 850
Wood—White Oak.	Cord—3 800 lbs.	14 000 000	4 100
Wood—Pine.......	Cord—3 000 lbs.	11 000 000	3 200
Wood—White Pine.	Cord—1 900 lbs.	7 000 000	2 000

Values for wood are necessarily approximate due to the many variables encountered. The average efficiency of gas and coal furnaces may be taken as 60 percent. A poor furnace will run as low as 40 percent while some exceptionally good ones will give about 75 percent.

To determine the electrical energy necessary to heat any given room or building, many factors must be taken into consideration. Heat is lost by transmission through walls, floor and ceiling and through air necessary for ventilation. The exposure of the building must also be considered. Losses by radiation may be calculated as shown in Table II.

These coefficients, for latitudes approximately that of Pittsburgh, will be increased as follows:—

10 percent for northern and windy exposure.
10 percent where building is heated during day time only, and building is not exposed.
30 percent where building is heated during day time only, and location is an exposed one.
50 percent where the building is heated intermittently during the winter months.

From these figures it is easy to calculate the heat lost by radiation only. This, however, does not include the heat lost due to ventilation. For the home it is usually considered sufficient to change the air once per hour. For other buildings the relative values given in Table III are considered good practice, although no standard allowance can be made to suit all cases, and the figures of the designer or architect should be used in all such calculations.

These figures are for uncontaminated air. Where

TABLE II—WATTS LOST BY RADIATION PER SQUARE FOOT OF SURFACE PER DEGREE F. DIFFERENCE IN TEMPERATURE.*

Radiating Surface.	Watts.
24 in. brick wall	[illegible]
12 in. brick wall	[illegible]
8 in. brick wall	[illegible]
4 in. brick wall	[illegible]
Wooden flooring	[illegible]
Wooden ceiling	[illegible]
Fireproof flooring	0.0360
Fireproof ceiling	[illegible]
Single window	[illegible]
Single skylight	0.300
Double window	0.170
Double skylight	0.185
Door (65 percent wood—35 percent glass)	0.170
Door—plain	[illegible]
Wood partition—1 in. thick	[illegible]

smoke, gas, gas illumination, etc., are present, additional provision must be made. A single gas burner consumes about 45 cubic feet of air per minute. To

TABLE III—AIR REQUIRED FOR VENTILATION OF PUBLIC ROOMS.

Service.	Cu Ft. of Air per Hour.
Hospitals	3 600 per single bed
Legislature assembly halls	3 600 per seat
Barracks, bedrooms and Workshops.	3 000 per person
Schools and churches	2 400 per person
Theatres and ordinary halls	2 000 per seat
Office rooms	1 800 per person
Dining rooms	1 800 per person

heat one cubic foot of air one degree F. requires 0.0054 watt-hours, or one kilowatt hour will heat 2 650 cubic feet of air 70 degrees F. From this the

*Figures are taken from "Ventilation and Heating" issued by B. F. Sturtevant Co.

energy necessary to heat the air required for ventilation may readily be determined.

A quicker method of determining approximately the amount of heat necessary to maintain the temperature of a room is given in the following formula:—

$$\left(\frac{W}{4} + G + \frac{C}{55}\right)\frac{T}{3.4} = \text{heat losses in watts}$$

where W = exposed wall surface in sq. ft.
G = exposed glass surface in sq. ft.
C = contents in cubic feet.
T = difference between inside and outside temperatures in degrees F.

This formula assumes that the building is of good construction with fairly thick walls, tight fitting doors and windows and no unusual conditions, such as exposure to high winds, etc. It is an approximation only for preliminary estimates and is not to be considered accurate for all cases.

FIG. 1—A WESTINGHOUSE HEATER OF THE LUMINOUS TYPE

The effiiency of electric heating depends upon the installation. If air heaters are used in each room, the efficiency is given as 100 percent. If a hot water or steam heating system is employed, supplied from one central boiler, the efficiency will depend upon the radiation from the boiler and supply pipes. Using immersion bayonet heaters and with the boiler and supply pipes well lagged to minimize radiation losses, the efficency should be from 90 to 95 percent—the loss of course heating the cellar or boiler room.

If a forced ventilation system is used and the building is heated by forcing air over and through electric heaters (preferably of the grid type), the efficiency should range about the same as for immersion heaters, under the same condition as regards heat insulation of the generating system.

In all calculations of the heat necessary to obtain a certain result, the character of the installation must be considered. For instance in a small store where the doors are opened often, an additional allowance should be made. In the home the loss from this may be neglected. The lowest outside temperature on record should always be used in these calculations.

Example—Office 15 by 15 by 10 feet—located at the northwest corner on the third floor of a four-story warehouse. The building has 12 inch brick walls—floors of fireproof construction, two windows each 18 square feet, one door 3 by 7 ft., a one inch wood partition. Temperature of office to be 70 degrees F.—balance of building 40 degrees F., outside, zero degrees F. Air supply 4 000 cubic feet per hour.

Then according to the above conditions:

				Watts
Exposed wall	264 sq. ft. by 0.0925 by 70 =	1710	10 percent +	1880
Exposed glass	36 sq. ft. by 0.355 by 70 =	900	10 percent	990
Interior partition..	300 sq. ft. by 0.12 by 30 =			1080
Ceiling	225 sq. ft. by 0.0425 by 30			290
Floor	225 sq. ft. by 0.036 by 30			240
Air	4000 sq. ft. by 0.0054 by 70			1510
			Total watts	5990

There should be used two 3-kilowatt air heaters, one under each window, each having three heat control.

Calculations for any application of electric heat for buildings can be made by a simple application of the various constants given herein, in the same way as in the example just given. To obtain a comparison of the cost of heating with electricity and various fuels it is only necessary to figure the electrical input as above and, with a given rate per kw-hr. the cost of operation can be approximated closely. By referring to Table I the corresponding amount of the specified fuel can be obtained and a comparison made, always bearing in mind, however, the difference in efficiency between electricity and the other methods.

It is not fair in such estimates to base a decision only on the relative cost of operation. The cleanliness, convenience and sanitary features of electric heat, the freedom from all noxious gases and fumes, the reduction of the fire risk, the elimination of any charges for removing ashes, etc., all should have a bearing on a decision.

Electric heat is acknowledged to be the ideal method wherever the means of the user or the low rates for power will permit its use. Many hydro-electric and some steam driven stations make rates that are within the reach of the average consumer, and wherever such rates exist, the field for electric heating should be carefully developed.

In making comparisons between electric and other heaters it must be carefully kept in mind that the efficiency of the air heater as a heater is 100 percent. This fact indicates that there can be no real difference in the efficiencies of air heaters of different makes. Owing to the extreme variations in local conditions encountered in this class of service it must also be evident that a definite guarantee of accomplishing certain results cannot be given, and that the engineer's estimate can be based only on his best judgment and the best information available concerning the installation at hand. If the user insists upon a definite guarantee he should be made to understand that the engineer can only make such a guarantee by allowing an ample margin of input over what is really considered necessary, in order to make sure that there is no possibility of insufficient heat supply, a condition which is always inadvisable on account of the useless extra cost to the purchaser of the electrical apparatus.

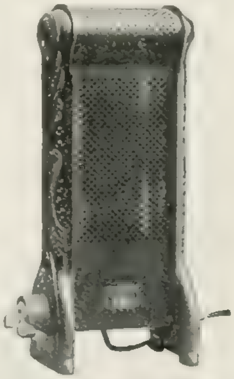

FIG. 2—A NON-LUMINOUS ELECTRIC AIR HEATER

Standardization in Industrial Illumination

A. J. AIRSTON

THE PLEA for standardization in industrial establishments is based on the desire for the most efficient and economical units and methods, and the best and cheapest results. In the field of illumination the need of more definite standardization has long been felt, and it is with a view of indicating the goal to which this desire is leading, as well as suggesting some practical ideas for the solution of the problem, that the present paper is presented.

IT IS necessary in the first place to decide what is meant by good illumination and then endeavor to deduce standards therefrom. The best possible light in which to work is that which gives the greatest comfort to the eyes or, in other words, which has the least possible deleterious effect on them. As no two persons have eyes alike, it would seem at first impossible to give ideal illumination from the points of view of any two individuals. However, if it were possible to produce light equivalent to that out doors on a cloudy day, i. e., diffused daylight, there are very few who would not agree that the lighting conditions under such circumstances were ideal. Such light is produced by an enormous mass at the very high temperature of 6 000 degrees C. or more at a great distance away, from which light has to pass through a screen of vapor or cloud before reaching the location under consideration. In other words, it is a semi-indirect system of illumination. Further, similar effects can be obtained by having the direct rays of the sun reflected from outside a building through windows on which the actual rays do not strike and this would then be an indirect system of lighting. When the sun's rays fall directly upon the working plane a direct system of illumination is produced but the light is too glaring for indoor work. Thus as regards daylight semi-indirect and indirect lighting are preferable to direct lighting.

FIG. I

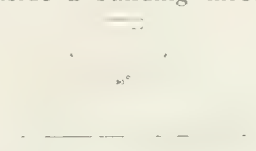

FIG. 2

FIG. I —DIAGRAM INDICATING THE ANGLES THROUGH WHICH LIGHT RAYS ENTER THE EYE

FIG. 2—SHADE OF THE CORRECT DESIGN TO PREVENT DIRECT LIGHT FROM ENTERING THE EYE

Referring now to artificial systems of illumination, without exception the light is produced by matter heated to incandescence, no light, such as that of the glow worm, having been produced artificially that is capable of being put to practical use. It is necessary, therefore, to decide how the artificial lights can be used to the best available advantage.

Illumination consists in projecting light waves from a source or sources so that they will strike the bodies to be illuminated, some light waves being absorbed and some being reflected. The latter enter the pupil of the eye, producing a picture on the retina so affecting the nerves that the picture is transmitted to the brain. The color of the light is dependent upon the length of waves produced and the varying wave lengths give all of the well-known color effects of the visible spectrum from red to violet, besides the invisible infra-red and ultra-violet rays. Daylight contains all of these rays and in such proportions as to cause an object to appear in its true colors.

The color of an object seen by reflected light is produced by the waves reflected from it and hence an absolutely black object appears so because it absorbs all the rays and reflects none. A blue object in a red light would appear the same as a black object, since none of the rays are reflected. Artificial lighting should, therefore, approach, as nearly as possible, to daylight in order to show objects in their accustomed colors; and, further, the effect on the eye should be such as to produce conditions similar to daylight, since it is for useful and not ornamental purposes that light is required in industrial establishments.

The eye has, through long usage, become accustomed to receiving light from an overhead source. The result is that its muscles adapt themselves to these conditions, becoming stronger in the upper parts of the eye, and the nerves becoming less sensitive. The effect of a bright light below the level of the eye is to cause an irritating glare, whereas the same light an equal distance above the level of the eye and yet still in the range of vision may cause practically no marked inconvenience. Any direct rays of light entering the eye are, however, objectionable.

The effect of glare on the eye is to produce headaches and consequent inefficiency, probably affecting the health of the individual and eventually impairing the sight. The troubles caused by inadequate illumination, due to too much, too little, or too concentrated light, are many and far reaching and the more thoroughly the subject of illumination is studied the more it is realized that the very best methods and forms of lighting are needed in order to produce the most beneficial results for mankind.

Even where there is no glare and the intensity is suitable, the effect of continuous light of one intensity only, or rather of rays composed of the same combination of wave lengths, for a long period, is to cause fatigue, since it gives no play to the muscles actuating the pupil and therefore the eye has no rest; there are no light and shade effects, no variations in color. This is especially noticeable when reading for a considerable length of time without taking the eyes from the pages, particularly if the paper be colored.

There are many different sources of artificial light, none of which, however, give a spectrum containing the complete set of wave lengths which form the spectrum of daylight. The three principal illuminat-

ing units are the incandescent gas mantle, the incandescent electric filament and the electric arc. These three are continually being experimented with and improved upon, until today their reliability is almost unquestioned. In addition to these units the vacuum tube lamps are also available, the only ones of which having been put to practical use as yet being the mercury vapor lamp and the Moore tube.

These four types of lamps are all being used extensively and in order to arrive at a conclusion with regard to standards and their application to industrial establishments in particular, the reasons for standardization should be considered. Until quite recently the problem of the illumination of a factory was solved by placing arc lamps at intervals and small carbon filament lights at particular locations where necessary. Glaring, flickering arc lights with uneven distribution and innumerable scintillating spots where small drop lights were being moved to and fro by workmen were the result. When the tungsten lamp came into use, the science of illumination took more rapid strides and, as the strength and durability of the filament and the size of the lamp was increased, so increased also the benefits which the illuminating engineer could give to the world by improvements in lighting methods and systems. And now, with the latest type of tungsten lamps, an economical and efficient installation, in which the illumination approaches very closely to that of daylight, can be designed and put into operation in almost any location.

FIG. 3 A WELL LIGHTED INTERIOR WITH WHITE WALLS

Standardization is necessary in order to make a system of illumination follow certain definite rules so that replacement may be easy and extensions may be as simple as possible. The æsthetic side which, however, counts for very little in industrial establishments, demands standardization to some extent. The economic side requires it still more and the question of efficiency calls for the best under the existing circumstances and therefore adds an additional reason for standard systems. From every point of view, then, there is the call for standardization.

In considering the lines along which standardization is feasible the systems and units in use at the present time must be studied. As before mentioned, there are the three distinct systems of illumination.

1—Indirect Lighting.
2—Semi-Indirect Lighting.
3—Direct Lighting.

The first screens the source of light from the observer so that only reflected light reaches the working plane. The second screens the source of light but allows a certain amount to diffuse through the shade whilst a considerable portion is reflected from the ceiling or a special reflector. The last and most common method, owing to its economy, is to place a shade or reflector around the light source so that with the direct and reflected light the great majority of the rays are thrown on the working plane.

The first system is perhaps the best if conditions permit of its installation, for the glare is reduced to a minimum. The great drawback, however, is the expense, since a much greater intensity of light is required from the source, and frequently a diffuser as well as the inverted reflector, owing to conditions making it impossible to use ceiling reflection. In addition, the fixture is a receptacle for dust, unless boxed in by glass which cuts off an appreciable percentage of the light, rendering the unit still more expensive. The uniformity of the diffused light and the absence of objectionable glare and shadows make the indirect system capable of giving the closest approximation to daylight of any form of artificial illumination.

The second system has the advantage of the first but in a lesser degree, together with the additional economic advantage of more light from the source on the working plane, since a considerable proportion diffuses through the shade. This carries with it the drawback of a certain amount of glare. The fixture is less expensive and more easily adapted to varying conditions than the former.

The third system is the one almost universally adopted for industrial purposes and gives the maximum amount of light on the working plane for a given consumption of power. Also the lighting fixtures for this type are the least expensive and the most easily adaptable to varying conditions, the only drawback being the glare. Further, the light can be projected on to particular spots and in particular directions. It thus lends itself peculiarly to special conditions where a light is required which will illuminate a small area at high intensity. To minimize the glare, the mounting height of the units in this system must be greater than that with either of the systems before mentioned, but in industrial establishments this is usually an advantage, owing to the fact that the light source is then advantageously placed in the position where the lamp is least liable to be broken. Furthermore, where white

ceilings and light surroundings are out of the question, and where belts and dark colored machinery absorb much of the light, and also where dust and dirt accumulate rapidly, the cost of the maintenance of the direct system, with its easily changed and cleaned reflectors, is as low as possible. From the point of view then of efficiency, expense, convenience and adaptability the direct system of lighting holds the field against the other two methods. Its drawback is the injurious effect of the glare on the eye and health of the individuals working under the direct rays from the source of light. This, however, can be made negligible by using the correct mounting heights and reflectors.

For industrial establishments then, neglecting the very few places where the artistic effect should receive recognition, it is well to standardize on the direct system. Having chosen the system the standardization of details should be given attention. The position of each unit should be such that the direct rays from the light do not come within the range of vision of the workman in his usual position. This range from the eye extends 45 degrees above the horizontal and 75 degrees below, as shown in Fig. 1, the head being considered as held rigid and the extreme points taken as seen in a vertical plane. Thus a bare light placed for the benefit of one individual alone should be in a position at least as far above his eye as it is in front when the maximum horizontal distance from the light which he is liable to assume when working is considered. It is obviously impossible to standardize mounting heights when using bare lights, especially when the case of individuals working near each other is taken into account. The reflector that is to be used on the lamp should also be considered. The one adopted should not reflect any light directly, outside a solid angle of 90 degrees, as shown at the right in Fig. 1, and further, the amount of light diffusing through the reflector should be small enough so that it will not appear objectionably bright.

FIG. 4—A SHOP INTERIOR WITH DARK COLORED SURROUNDINGS

The actual wattage of lamps per square foot in this location is twice as great as that in Fig. 3.

The spacing distances of the lights are the next consideration and in order to obtain them the effect of shadows must be the chief consideration. In offices, desks are liable to be placed within a distance of seven feet from center line to center line and direct lights must therefore not be a greater distance apart than this in any direction. In factories the distances apart of machines or benches must be taken into consideration and eight feet is a safe minimum, although in the majority of cases 12 feet or even more may be taken as one standard, providing ceiling heights permit the use of lamps of sufficient intensity.

The standardization of mounting heights is the next point to be decided upon and again the 90 degree solid angle reflector must be considered. This prevents direct rays from the source striking the eye under the normal conditions whatever may be the mounting height, for if the source be below the plane previously considered with reference to a bare light, the reflector screens the glare, and if it be above, it is out of range of vision. Attention must therefore be given to considerations of intensity of illumination on the working plane, excessive glare just beyond the normal range of vision, and reflected glare from objects in the range of vision.

Diffused daylight mentioned in the earlier part of the paper gives illumination of high intensity. To produce this intensity with direct lighting and average ceiling heights would mean excessive glare. Therefore intrinsic brilliancy, and hence the type of lamp, enters into the question of standardization of mounting heights; moreover, since low intensities give adequate illumination in many locations, the question of economy must also be taken into account.

Theoretical considerations do not altogether govern efforts at standardization. Further deductions based on experience should also be taken into account. At the present day the tungsten filament lamp, in its varying sizes, length of life, strength of filament, adaptability and economical possibilities of usage, is superior to all others. The direct system with tungsten lamps is thus the best standard, and the questions of standard mounting heights, spacing distances, etc., for varying conditions become the next consideration.

Every location should be separately considered and the list of standards decided upon should be sufficient to cover all features which may be presented, the majority of which may be suggested by Table I and the following list:—

1—Area of location.	4—Type of ceiling or roof.
2—Shape of location.	5—Color of ceiling.
3—Height of ceiling.	6—Type of walls, if any.

7—Color of walls.
8—Class of work carried on in location.
9—Type and color of furniture or machinery.
10—Obstructions between working plane and ceiling or roof.
11—Possible locations for switches.
12—Requirements of safety and health, for wiring, piping and positions of lamps.
13—Color of light best adapted to conditions.
14—Type of light best adapted to conditions.

For drafting rooms, the semi-indirect system is often used. The light diffusing through the reflectors, and reflected from light ceilings and walls gives an almost entire absence of shadows. An excellent example is given by the use of clusters of four 60 watt lamps on fixtures placed eight feet apart, opal glass reflectors being used, which throw the light upwards,

the mounting height being 14 feet and the ceiling height 16 feet.

In Table II, the "watts per square foot" for various classes of work are based on figures obtained

TABLE I—RELATIONS OF LAMP SIZE, LIGHTED AREA AND LOCATION DIMENSIONS

Mounting Height in Feet	Size of Lamps in Watts W	Watts per Sq. Ft., w	Ideal Spacing Distance $\sqrt{\frac{W}{w}}$	Minimum Spacing Distance	Maximum Spacing Distance
7 to 10	40	0.5	9′ 0″	8′ 0″	10′ 0″
		1.5	5′ 2″	4′ 6″	6′ 0″
		2.5	4′ 0″	3′ 9″	4′ 3″
8 to 12	60	0.5	11′ 0″	9′ 6″	12′ 9″
		1.5	6′ 4″	5′ 6″	7′ 3″
		2 5	4′ 11″	4′ 6″	5′ 6″
10 to 14	80	0.5	12′ 7″	10′ 6″	15′ 0″
		1.5	7′ 4″	6′ 6″	8′ 3″
		2.5	5′ 8″	5′ 0″	6′ 6″
12 to 16	100	0.5	14′ 5″	12′ 6″	16′ 0″
		1.5	8′ 2″	7′ 0″	9′ 6″
		2.5	6′ 4″	5′ 8″	7′ 0″
14 to 20	150	0.5	17′ 4″	15′ 0″	20′ 0″
		1.5	10′ 0″	9′ 0″	11′ 0″
		2.5	7′ 9″	7′ 0″	8′ 6″
17 to 27	250	0.5	22′ 5″	20′ 0″	25′ 0″
		1.5	12′ 11″	11′ 9″	14′ 8″
		2.5	10′ 0″	9′ 0″	11′ 0″
25 to 35	400	0.5	28′ 2″	25′ 0″	31′ 6″
		1.5	16′ 4″	15′ 0″	17′ 9″
		2.5	12′ 7″	11′ 6″	13′ 6″
30 10 40	500	0 5	31′ 7″	28′ 0″	35′ 6″
		1.5	18′ 6″	16′ 6″	20′ 9″
		2.5	14′ 2″	12′ 6″	15′ 0″

from actual installations. The size of lamp, decided upon from Table I, and the "watts per square foot" from Table II, lead us to deduce an "ideal spacing distance *d*." This assumes the lamps placed on the corners of squares throughout the location and is therefore

$$\text{the square root of } \frac{\text{wattage of lamp}}{\text{watts per square foot}}$$

This may be made clearer by an example. Assume that it is required to light an office for close

TABLE II—AMOUNT OF ILLUMINATION REQUIRED ACCORDING TO CLASS OF WORK

Class of Work	Watts per square foot
Office, General	1.4
Close Work	1.7
Curve Work	2.5
Drafting	3.5
Vaults	1.5 to 0.75
Corridors	0.5
Power House	1.2
Average Machine and Bench Work	1.5
Particular Machine and Bench Work	2.0
Storerooms	3 to 1.5
Inspection	2.5
Woodwork	2.0
Tool Rooms	1.5

work, ceiling height 10 feet. From Table II the intensity of illumination is given by 1.7 watts per square foot. From Table I the size of lamp required for a ten foot ceiling is the 60 watt.

$$\text{Then } d = \sqrt{\frac{60}{1.7}} = 6 \text{ feet}$$

That is, the lights should be spaced six feet apart in each direction. The condition of surroundings and class of work are the most potent factors to be considered in deciding upon the watts per square foot to be used. However, the difference in light and dark surroundings, furniture and machinery may cause a variation up to 25 percent in the actual intensity of light on the working plane. The percentages of light absorbed by one reflection by different colored wall papers are given in Table III. The area and shape of the location and position and size of any obstacles must also be given due consideration. In offices where desks are placed along the walls a row of lamps should always be hung within two feet, nine inches from each wall. Lamps near windows should not be wired on the same switch as lamps a considerable distance away. Referring again to Table I, the ideal spacing distances are given for three values of w for each size of lamp, and in the last two columns the maximum allowable variations are indicated.

The cost of the installation is by no means a small consideration and has its due effect in guiding the designer. A basis for approximate estimates may easily be made after a little experience which will give the cost per lamp installed complete. If n = number

TABLE III—ABSORPTION TABLE FOR VARIOUS COLORED WALLS

Kind of Paper	Percent Absorption
Foolscap paper	30
Orange	50
Yellow wall paper	60
Light pink paper	64
Light blue paper	75
Brown	80
Blue green	88
Deep Chocolate	96

of lamps for a location and A = area, then using the same notation as before $n = \frac{Aw}{W}$. This multiplied by the base cost c for the type of lamp in question gives an idea of the total cost of the installation C.

A set of standard rules may thus be formulated to guide the designer in his efforts to lay out a system of illumination for a location in an industrial establishment.

1—Measure up the location, making a rough sketch of plan and elevation showing ceiling or roof trusses, positions of windows, obstacles which may affect the installation, present outlets and switches, if any, and giving full dimensions.

2—Make a note of color and condition of walls, ceiling, furniture, machinery and equipment as well as the class of work carried on and the closeness of application required, for guidance in deciding the intensity of illumination to be used.

3—a—Draw up plans to scale.

b—Decide a size of lamp and mounting height.

c—Assume watts per sq. foot to be used.

d—Deduce ideal spacing distance $d = \frac{W}{w}$

e—Lay out position of lamps on plan to give regular spacing distances, installing a row within two feet nine inches of each wall in office, and approximating as near as possible to the ideal spacing distance in both directions.

f—Make a tracing, from the plans, showing boundaries of the area, old outlets, wiring and switching and proposed new outlets wiring and switching.

g—Specify sizes of lamps and reflectors and give mounting height and also bill of material and any further necessary instructions for wiremen.

h—Show control of lamps by numbering all on one switch the same.

4—Check up the design in every detail at the actual location and see that each lamp and switch is effective and free from all obstacles.

5—Deduce approximate cost $C = nc$.

By these rules the designer will be enabled to illuminate almost any location in an industrial establishment and the result will be a system in accordance with the theoretical principles already discussed.

Ventilation by Means of Small Motor Driven Fans and Blowers

BERNARD LESTER

ONE OF THE MOST interesting phases in connection with our modern method of living is the attention we give to obtaining those necessities of life which in earlier days were looked upon as freely obtainable to every one, such as pure water, plenty of light and pure air. Large sums of money are spent in obtaining these necessities, while years ago they were looked upon as benefits open to every one, as is shown in the old expression, "Free as the air we breathe."

THE INCREASED necessity for fresh air has come about principally through three changes in the conditions under which we live. In the first place, our method of living throws individuals together in groups and masses much more frequently than formerly. In business, society, education, amusements and traveling our activities are carried on in groups and continually many persons are gathered together indoors and often in one room. We have our business conferences together, we ride together in the public conveyance, we are educated in groups, we amuse ourselves together and we eat together. In fact, a large share of our time is spent indoors, and usually with our fellow beings.

In the second place the conveyances, schools, offices and factories in which we spend our time are constructed much differently than years ago. The old

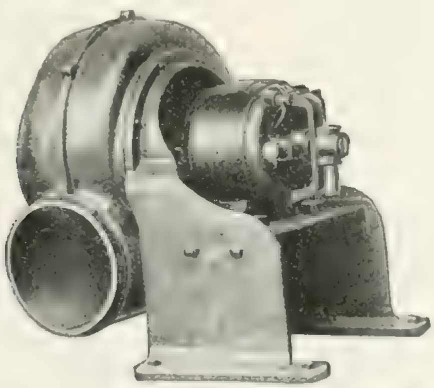

FIG. 1—A DIRECT-CURRENT MOTOR-DRIVEN SIROCCO BLOWER. SUCH IS COMMONLY USED FOR VENTILATION

school house with its stove in the center of the room, and its rattling and leaking window frames has been replaced with a structure which, for all intents and purposes, is air tight, and is supplied automatically with a definite quantity of air kept between certain limits of temperature and humidity.

In the third place we have recognized the advantage gained by plenty of fresh air supplied to us at correct temperature and correct humidity. This is necessary not only in preventing disease but in increasing the efficiency of the human body and mind. Such recognition has crystallized in many quarters into legislation. In most states laws have been made requiring that all school buildings be supplied with a definite number of cubic feet per minute of fresh air per individual occupant. Similar state laws and city ordinances apply to other buildings, such as sweat shops, moving picture shows, business offices and hospitals. An acknowledged standard has become adopted which dictates that approximately 30 cubic feet of fresh air per minute be supplied a given room for every occupant.

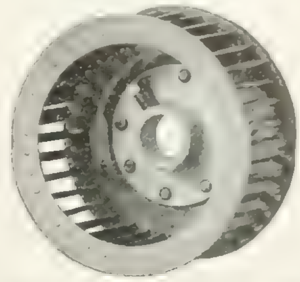

FIG. 2—ROTATING ELEMENT OF BLOWER SHOWN IN FIG. 1

The temperature for comfort is influenced directly by the humidity as is the healthfulness of the air. A test recently made in a school room in Chicago showed that the limits of comfort existed between temperatures from 64 to 70 degrees F. with corresponding relative humidity of 55 to 30 percent. With the careful analysis which is being given to industrial efficiency the comfort and healthfulness of employes can be reduced directly to terms of increased profits from capital invested.

With such conditions as these existing it will become obvious that there has come about a large demand for small electrically-driven units which will assist in efficient heating, accomplish satisfactory ventilation and produce cooling effects, where such are de-

FIG. 3—INTAKE END OF MOTOR DRIVEN VENTURA FAN SHOWING MOTOR MOUNTING.

sirable, to bring about normal working conditions. This demand is due, in a large measure, to the fact that there are a number of buildings erected in the past with little provision made for obtaining these results. In these, the installation of a complete ventilating system, such as would be placed in a modern

building, with necessary fans and blowers, piping systems, ducts, etc., would be excessively expensive and often almost impossible without the reconstruction of the building itself. Even in new heating and ventilating installations, small blowers and fans may be used to meet special conditions as in the ventilation of toilet rooms, laboratories and kitchens. One of the chief reasons for the necessity of these is the fact that these ventilating units are directly under the control of the user rather than under the control of the individual operating the entire ventilating system. Conditions often arise where such control is an absolute necessity.

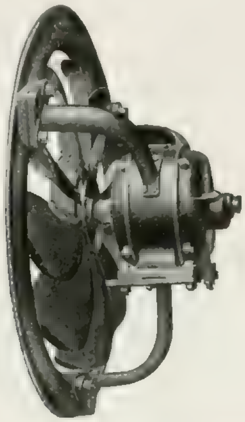

FIG. 4—SIDE VIEW OF OUTFIT SHOWN IN FIG. 3

The common type of small ventilating sets consists either of a motor-driven disc ventilating fan, usually mounted in the wall, or else a motor-driven blower consisting of a blower wheel, blower housing and motor mounted with pedestal for its support in one unit. The latter outfits are usually mounted upon the floor or upon a wall bracket.

Like most types of fans the power required to drive a disc ventilating fan increases rapidly with an increase in speed, usually as the cube of the speed. Assuming a constant speed, the power required to drive it increases as the flow of air is restricted either by a counter air pressure or else resistance offered by the use of a piping system. The disc fan is not sufficiently positive in its operation for use where there is an extensive piping system, and consequently cannot be successfully employed in supplying air for heating and ventilating systems extending throughout the buildings. This type of fan is, however, signally successful in supplying fresh air to individual rooms, stores or workshops, or in similar places where it is more desirable to exhaust large quantities of impure or heated air, or air laden with gases, smoke or obnoxious fumes. Even when so employed, however, motor driven disc fans may be subject to overloads, as in the case of a fan placed in the wall exhausting out of doors against a strong wind. To meet such overload conditions the more successful types of motor driven disc fans are designated with sufficient motor capacity to operate successfully when the area of the outlet or inlet is reduced to approximately two thirds normal. Totally enclosed motors should be used with fans of this type, for air laden with dust, dirt, or moisture is likely to be drawn over the motor. Series wound direct-current motors can be successfully used.

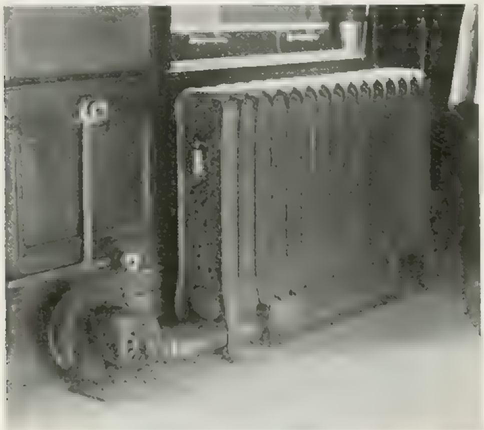

FIG. 5—BLOWER OUTFIT IN CONNECTION WITH A RADIATOR ALREADY INSTALLED

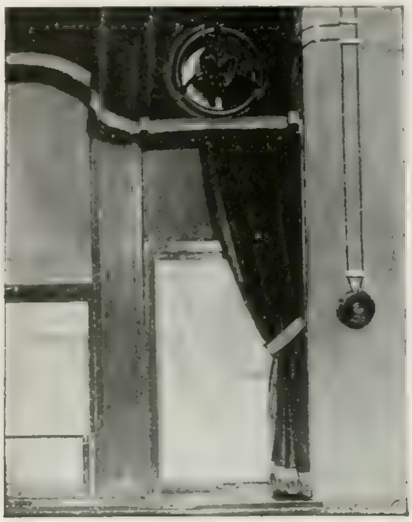

FIG. 6—A VENTILATING OUTFIT CONVENIENTLY LOCATED IN A CLUB ROOM

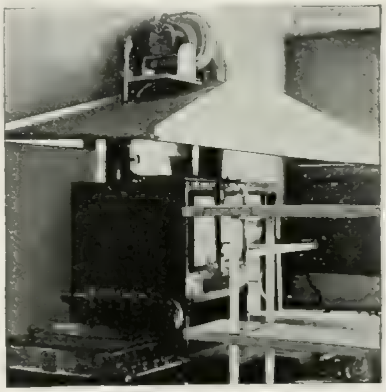

FIG. 7—REMOVING SMOKE AND ODORS FROM A KITCHEN BY MEANS OF A BLOWER OUTFIT

The operating characteristic of the small utility blower, as typified by the Sirocco type, differs from that of the disc ventilating fan. The power required to drive it increases with an increase in speed, but as soon as resistance is offered to the flow of air there is a decrease in the power required to drive the blower.

Consequently if such a unit is supplied with a motor of ample capacity to operate the blower with inlet and outlet wide open, there is no danger of overload when resistance is offered to the flow of air. Obviously

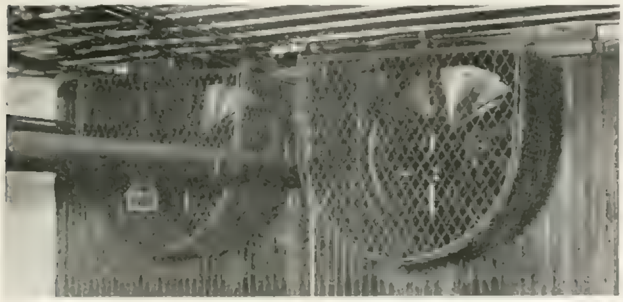

FIG. 8—TWIN FANS VENTILATING THE BASEMENT OF A LARGE DRYGOODS STORE

series wound direct-current motors cannot be successfully used with these blowers. Since the air handled by the blower is not drawn over the motor, there is no necessity to use totally enclosed motors with these units unless the unit itself is to be placed where it will be particularly subject to dirt or moisture.

Since the volume or air delivered by both types of ventilating units greatly increases with an increase in operating speed, in the interests of economy as high operating speeds as possible are selected. The limiting feature for most applications is quiet operation. For all ordinary classes of service these units must operate quietly and the output of the fan or blower could be increased materially were noisy operation permissible.

FIG. 9—REMOVING DANGEROUS FUMES FROM THE HOOD IN A CHEMICAL LABORATORY

The use of disc ventilating fans and utility blowers has increased remarkably during recent years. Disc fans are being used almost universally in restaurants, moving picture shows, laundries, bakeries, textile plants, chemical plants and for other similar service. The illustrations shown herewith are simply typical of installations chosen at random. The use of the motor-driven utility blowers has been largely limited heretofore to the ventilation of telephone booths, toilets, steamer cabins, club rooms, for exhausting fumes above kitchen ranges or from hoods used in chemical laboratories. More recently, these units have been employed for office ventilation. Fig. 5 shows one of a large number of duplicate units installed in a large office building for supplying fresh air in connection with radiators already installed. The fresh air ducts leading from the outside through the wall to the radiator were found to supply an insufficient quantity of air, and the flow of air was irregular and unsatisfactory since it depended largely upon the direction of the wind and other outside influences. Ventilation by means of a number of these small units was obtained

TABLE I—VOLUMES OF AIR RECOMMENDED

Room	Complete change of air every	Number of cu. ft. of air per minute per occupant
Hotel dining room, restaurant............	5 to 10 minutes depending on height of ceiling	
Offices, living and sleeping rooms, halls, schools, etc............		20 to 30
Smoking rooms..........		30 to 50
Kitchens, laundries, laboratories, etc.......	1 to 3 minutes	
Telephone booths, bank vaults and very small rooms............		20 to 30
Sick rooms................		30 to 50
Moving picture theaters........................		20 to 30
Operator's booth in moving picture theatre........................		20 to 30

Kitchen and laboratory should have a hood over the range or place where fumes emanate, with an outlet pipe of the diameter of the fan ring.

In laundries the fan, if used for exhausting, should be as low in the wall as possible so that the heavy, moisture-laden air will be drawn out of the room. Seven feet above the floor is a good height for safety as well as for good results.

at a comparatively small cost and without the necessity of reconstructing any part of the building. A remarkable increase in operating efficiency of the office force was obtained by the installation of these units.

Several units of this kind have been built in the walls of small hospitals used in some of the large steel plants. With a filter box equipped with a cheese cloth screen, the air is purified before being taken indoors. A reversing mechanism permits the use of this outfit as an exhaust.

In selecting the proper capacity of fan for a particular case, it has become customary to base this upon the "change of air" method or "number of occupants" method. In kitchens, laundries, dining rooms, etc., it is customary to first decide how often the air should be changed and then select a fan of sufficient capacity to supply an amount of air equal to the cubical contents of the room within the approximate time limit selected for the air change. For offices, halls, schools and moving picture shows where the number of occupants can be determined closely, the number of cubic feet of air supplied the room is based entirely on this. Table I indicates common practice.

Charging Apparatus for Automobile Lighting Batteries

Q. A. Brackett

Not long ago the field for battery charging rectifiers was almost entirely limited to the charging of the batteries of electrically driven vehicles. Nowadays, however, the use of small storage batteries for the electric lighting of gasoline automobiles has become almost universal and a new field for rectifying apparatus has been opened up. While the size of the rectifiers required for this service is much

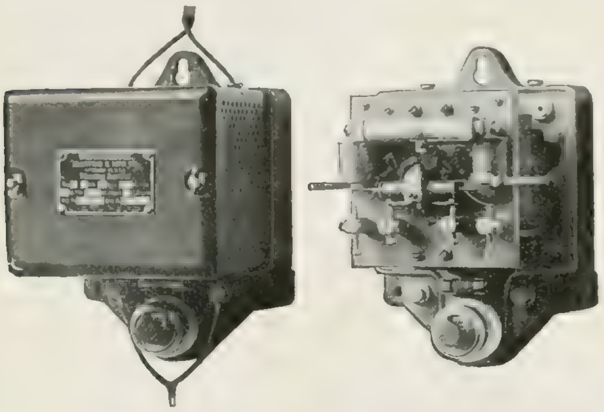

FIG. 1—SMALL VIBRATING TYPE OF RECTIFIER WITH AND WITHOUT COVER

less than for electric vehicle charging, the relatively much greater number of possible users makes this new application one of great importance.

While many cars having electric lights are equipped with small generators which are driven by the gas engine, when the latter is running, and intended for keeping the battery charged, nevertheless there are many cars not so equipped. For these some convenient means for recharging the batteries is absolutely necessary, not only for the private user, but for the large garage as well. Then, too, even those batteries normally kept charged by a generator on the car need occasional extra charging. All such automatic systems employing generators driven by the gas engine can be designed to suit only average conditions. If a car owner drives mostly at night with his lights on he will drain his battery faster than he charges it. If he runs mostly in crowded city streets or over rough roads where low speeds are compulsory, his battery will get little or no charging from the generator unless it is specially designed for these conditions. Likewise if a car is left standing idle for long periods at a time as during the winter months or while the owner is out of town, a battery will become badly run down and need special charging. For this purpose some car owners prefer a simple inexpensive device with which they can do this occasional or regular charging themselves, while others will prefer to have it done for them at some nearby garage.

Still another field is opening up this year in the application of storage battery lighting on motor cycles. The advent of the new cycle car also will still further increase the number of people who will have small batteries to charge, as starting motors, charging generators, etc., are rather incompatible with the low cost, simplicity and compactness of these light cars and motor cycles.

The problem then resolves itself into providing a small, simple, inexpensive charging device which the individual car owner can use at home for charging the one battery of his car himself, and a larger outfit suitable for large garages and capable of charging any number of batteries that may be on hand. In what follows certain outfits of various types that have re-

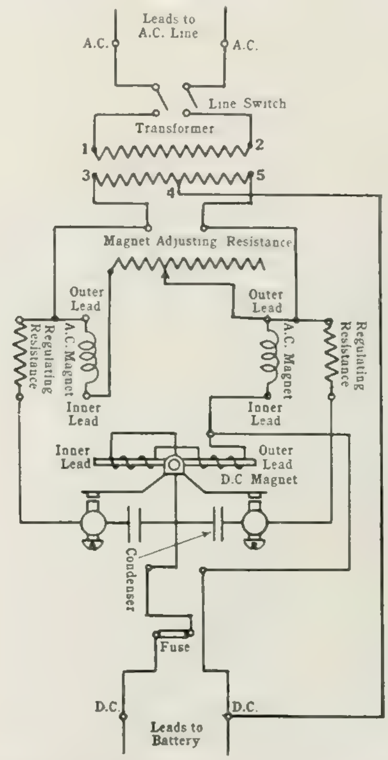

FIG. 2—WIRING DIAGRAM OF RECTIFIER SHOWN IN FIG. 1

cently been developed to fill the above requirements will be described.

Probably the smallest, simplest and least expensive type that could be developed for charging a single battery at home is the vibrating type of rectifier, one form of which is illustrated in Fig. 1. This device is really a small vibrating switch operating on the low voltage side of a transformer of suitable voltage for

the battery to be charged. This switch reverses the connections of the low voltage alternating-current circuit every time the alternating current reverses so that as a result the current through the battery always flows in the same direction. Fig. 2 shows the wiring diagram of a rectifier of this type and will serve to make its operation clear. A small two-winding transformer steps down the voltage of the line to a value suited to the battery to be charged. Energized by this low voltage secondary are two alternating-current stationary magnets connected in series with each other and with a small adjustable resistance. Opposite them is pivoted an armature energized by direct current from the battery. As the two ends of this armature are always of opposite polarity, while the alternating-current magnets are so connected that on each half wave of the alternating current they present the same polarity to the armature, the latter is attracted by one alternating-current magnet and repelled by the other, the effect being reversed each half wave. This causes the armature to vibrate in synchronism with the alternating current, the vibration being con-

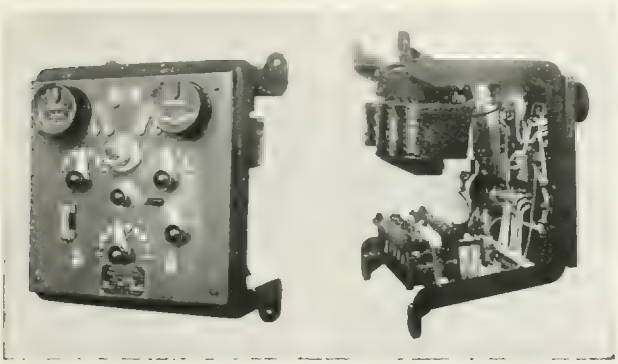

FIG. 3—COMPLETE TEN AMPERE CHARGING OUTFIT FOR BATTERIES OF FROM ONE TO TEN CELLS

trolled by a compression spring near each end. Near each end of the armature are mounted iridium-platinum contacts which make contact at alternate half waves with a pair of similar stationary contacts. These latter are connected to the two ends of the transformer secondary, while the battery to be charged is connected between the middle point of the secondary and the middle point of the vibrating armature. During one-half wave, then, the current flows from one end of the transformer secondary through the small resistance, (used to give the charging current the proper "taper") to one of the stationary contacts, thence into one end of the armature and out the middle point into the battery and back to the middle point of the transformer. The next half wave the operation is the same, except that the current comes from the other end of the transformer secondary, through the other small resistance and across the other pair of contacts. One great advantage of this design, where the armature is polarized directly by the battery, is that the user need pay no attention to battery polarity as a reversal of the battery connections reverses the polarity of the armature, and as a result the current always flows into the battery in the right direction irrespective of the connections. In fact, frequent reversal of the battery connections will be of advantage as it will give more even wear of the contacts,—an advantage that would not be available with a rectifier of fixed polarity where a permanent magnet is used.

Any rectifier of the vibrating type, if it is to be successful, must be timed to make and break contact at just the right time on the alternating-current wave. If not there may be more or less reverse current and sparking at the contacts. Since this adjustment often needs to be slightly different for different circuits a small adjustable resistance is provided in series with the alternating-current magnets which controls the vibration and makes it possible to readjust the rectifier quickly and easily to suit any available circuit within its rated range. Another feature of convenience is the arrangement whereby the screws that fasten the face plate to the main casting are utilized to make all necessary connections between the two parts of the outfit. Thus the removal of these four screws breaks all connections both electrical and mechanical, and allows the face plate bearing the vibrating mechanism to be entirely removed for inspection or repair if ever necessary.

The rectifier described above utilizes both halves of the alternating-current wave. Even at that, however, the direct current consists of a series of interrupted pulsations, since it is zero during the instant when the armature is moving from one pair of contacts to the other. As a result the direct current has a form factor that is rather high—about 1.4 in fact—which means that its heating value is higher than its chemical value, although it is the latter that is of use in charging a battery. This, however, is not sufficient to be serious and is far outweighed by the advantages of this type of rectifier in simplicity, small size, low cost and convenience. In the case, however, of vibrating rectifiers that utilize only one-half of the alternating-current wave, the danger of overheating the battery becomes serious, as the form factor is then about 2.0 and the heating effect is, therefore, about four times as great as with plain direct current of the same chemical value.

While it costs all the way from 25 cents to $1.50 to get a battery charged at a garage, according to locality, the use of a vibrating rectifier at home makes it possible to charge a battery at a cost only slightly over one cent an hour at a 10-cent rate for current. This low operating cost will allow the rectifier to pay for itself in a very short time, to say nothing of the convenience of not having to visit the garage each time the battery needs to be charged.

Another type of rectifier that can be used by the individual owner, and which is also suitable for those garages that have only a small number of batteries to charge at a time, is shown in Fig. 3. This is of the Cooper-Hewitt mercury type and is designed for

charging any number from three to ten lead cells. Simple connections are provided at the top of the panel that enable it to be used on either 110 or 220 volt circuits of any frequency from 40 to 133 cycles. In order to gain compactness and save floor space, the outfit has been designed for wall mounting and is entirely self-contained. On the main casting are mounted a small auto-transformer having suitable primary and secondary taps, and below it a small resistance box. On the front is the main panel of slate carrying the line switch, meters, control dials, etc. At the top of the panel are located the line terminals and the link connections for changing from 220 to 110 line volts. Just below in the center is a snap-switch for connecting and disconnecting the outfit from the line, and just below it the knob for tilting the bulb in starting. On either side are the two three-point dial switches that control the secondary taps of the transformers that go to the anodes of the bulb, while below in the center is a third dial switch of six points that controls a small resistance in the direct-current circuit. Coarse adjustment of the outfit to suit the number of cells to be charged and the current desired may be made by means of the two upper dials controlling the transformer taps, while finer steps of adjustment may be made by means of the lower resistance dial. The use of a resistance for this purpose is much simpler and cheaper than a reactance, and on small outfits like the one in question simplicity is more important than efficiency. As a matter of fact the waste in the resistance will be only from 0.1 to 0.5 of a cent an hour at a 10-cent rate for current, which is entirely negligible.

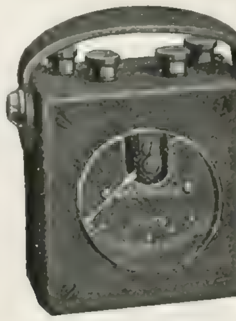

FIG. 4—DIRECT READING VOLTMETER OF POCKET SIZE FOR BATTERY TESTING AND SIMILAR WORK

FIG. 5—COMBINATION POCKET VOLTMETER AND AMMETER SUITABLE FOR BATTERY WORK

This outfit is designed for a direct-current output of 10 amperes and will operate at as low as three amperes. It may be used by the individual for charging a single three-cell lead battery or a five-cell Edison battery or for charging two or three such batteries in series if spare batteries or batteries from other cars are on hand. In the small public garage, the ability to charge three lead or Edison batteries at once, at a 10 ampere rate, will make it very useful, while the ability to charge either one or two batteries at a time will make it possible to give each battery just the right amount of charge. The outfit is not ordinarily equipped with meters, but if at any time meters are desired they are easily added, as shown in the illustration, as the panel is drilled and wired for them and dummy studs inserted in their place. It is but a moments work to remove these and substitute the meters.

When a number of batteries are to be charged in series, it is desirable to know the voltages of the separate batteries. For this purpose a portable voltmeter is most convenient and to fill the need for a high-grade meter for this service at a low cost a special line of portable meters has recently been gotten out. These instruments operate on the D'Arsonval principle, having a moving coil and a permanent magnet, and are especially well damped and consequently easy to read. Jeweled bearings and careful design have made available an instrument of an accuracy within one percent of full scale value yet of very small size and low cost. Fig. 4 shows a voltmeter of this style, while Fig. 5 shows a voltmeter and ammeter in one case.

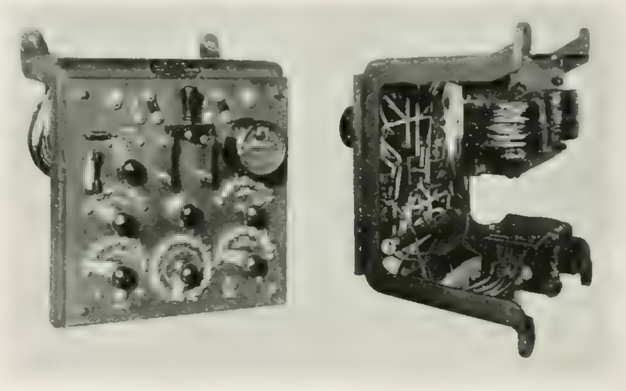

FIG. 6—FRONT AND REAR VIEWS OF A SPECIAL MERCURY RECTIFIER

In Fig. 6 is shown a rectifier that has been especially designed to fill the needs of the larger garages that may have quite a number of batteries to charge at once, yet often have just a few or even only one needing attention. On account of the very widely varying requirements of such garages this outfit has been designed with a greater flexibility of control and wider range than any other outfit ever before offered commercially. This has been accomplished by the use of a transformer design and starting system that are quite novel in rectifier work. The problem encountered was to make an outfit that would operate equally well on either 110 or 220 volts and have the same range and operating characteristics on each. Hitherto

most rectifiers built for operation on both 110 and 220 volts have been more or less of a make-shift on one voltage or the other, except in the case of a few small outfits of limited range, and the operating characteristics and charging range have been distinctly different on the two voltages. This has been because of the fact that the primary transformer taps used for voltage control gave entirely different results on 220 volts from what they did on 110. In the design here described, therefore, all voltage control for charging over the whole wide range is accomplished by means of taps on the transformer secondary, while no primary taps are used whatever, except for changing from 110 to 220 volts. To have covered a very wide range with secondary taps only would have required an excessively large number of taps were it not for the scheme shown in Fig. 7 where the secondary winding is broken near each end outside the primary taps and the breaks bridged through the control switches. Thus on each side of the neutral there are two dial switches, one controlling the secondary taps from the neutral out to the break in the winding and the other

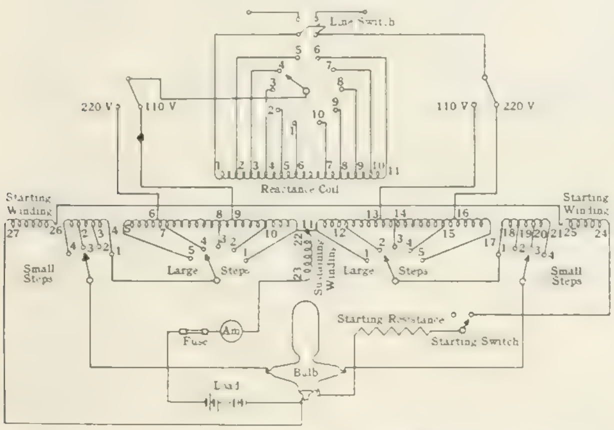

FIG. 7—WIRING DIAGRAM OF SPECIAL RECTIFIER SHOWN IN FIG. 6

controlling secondary taps on the small end winding beyond the break. These switches are so interconnected that they may be used independently of each other. The inner switch gives large steps of voltage control while the outer switch gives small steps so proportioned that its complete range is about the same as one large step on the inner dial. The total number of adjustments is, therefore, not the sum of the number of dial switch points, but their product. This scheme, therefore, gives a very wide range of adjustment with a reasonable number of taps, especially if the taps on the two sides of the transformer are slightly staggered instead of being symmetrically located.

The outfit illustrated in Fig. 6 can be used on either 110 or 220 volts and has the same characteristics and range on either voltage. Change from one voltage to the other is provided for by means of link connections near the top of the panel, while a line switch serves to connect or disconnect the outfit from the line. All voltage control for charging different numbers of cells is obtained by means of taps on the secondary as described above, and is accomplished by means of the four upper dial switches shown. The two upper are small step switches, while the two lower control large steps. The dial switch in the center at the bottom of the panel controls taps on a small reactance coil that is connected in series with the primary of the transformer. Half the taps are for use with 110 volts and the other half for 220 volts. The purpose of this reactance is to give "bad regulation" to the transformer. This is something ordinarily avoided in transformer practice but is just what is wanted for battery charging, since if no resistance were used the current would taper off to zero before the battery was wholly charged. By proportioning the amount of reactance used to the number and kind of cells to be charged the current can be caused to taper off during a complete charge to any value desired. Rectifiers for ordinary electric vehicle charging are usually permanently adjusted to have the same percentage reactance throughout their range, but because of the widely different sizes and makes of cells for automobile lighting that a garage would have to handle, including both lead and Edison types, a special dial has been provided whereby the user can adjust the reactance to suit himself. The outfit shown is designed for charging from one to twelve 3-cell lead batteries in series, or an equivalent number of Edison batteries, and has special provision also for charging one single cell when desired. It is thus possible for a garage to start off charging twelve three-cell lead batteries in series and cut these out of circuit one by one as they become completely charged, readjusting the outfit each time to suit by means of the dials controlling transformer and reactance taps, and without the use of any series resistance whatever. In case, then, one of the batteries has one low cell that needs extra charging it is also possible and easy to readjust the dials so that the outfit will finish the charge even of this one cell. The outfit is conservatively rated at five amperes direct current, and is especially designed for charging the small batteries on motor cycles, but a similar outfit for ten amperes and one to six 3-cell batteries could of course be made. The current delivered is indicated by an ammeter mounted on the panel, but a voltmeter is not furnished because when a large number of small batteries are charged in series the overall voltage is meaningless. For such conditions a portable voltmeter, like that shown in Fig. 4, should be used, and the voltage of each battery measured separately.

The starting system used with this rectifier is also extremely novel. The customary method with hand-starting outfits is to use a resistance connected between the starting anode and one of the main anodes. Thus when the bulb is tilted so as to bring the two mercury pools together, an alternating current flows from one pool to the other inside the bulb. When the bulb is allowed to tilt back, thus separating the mercury pools, this current is interrupted and a spark occurs at the surface of the mercury. If the main pool is positive

at that time nothing happens and the bulb does not start. If, however, it is negative and the dials are properly set the bulb should start. This scheme works fairly well on outfits of a moderate range in direct voltage, but is entirely hopeless on an outfit like that in Fig. 6, which is designed for charging from one to twelve 3-cell lead batteries and has provision for charging one single cell also. This is for two reasons: —First, either the resistance must be changed for different numbers of cells—which is too bothersome in a public garage where the number of cells to be charged may be different each time—or the starting current will be widely different when charging various numbers of cells since it varies directly with the direct voltage. In the outfit above mentioned, that charges from one to thirty-six cells, the current in the latter case would be approximately thirty-six times as great as when adjusted for charging one cell only. The second reason is that a spark is not effective in causing a bulb to start up even though the current is as high as usual, unless the voltage of the spark is fairly high also. In the case in question if the outfit were adjusted for charging one cell, the starting spark using the usual system would be too feeble to be effective even if high in current value.

This trouble is overcome, however, in the new design by making the starting spark of the same intensity under all conditions. This is accomplished by taking advantage of the fact that the volts-per-turn of the transformer remain constant since primary taps are only changed to suit changes of line voltage. Therefore, a separate small secondary winding on the transformer always develops the same voltage independent of how many cells are to be charged or how the secondary dials are set. Such a winding is accordingly provided of such a voltage as to insure a vigorous, effective starting spark, and it is connected to the two mercury pools through a resistance that limits the current to a suitable value when the pools come together. The resistance is also sufficiently high to prevent the main arc from starting on the smaller mercury pool when the spark happens to make that one negative and thus rectifying through the starting resistance and winding. With this starting system the bulb will start up equally well on any number of cells, which is a great improvement over previous designs.

To summarize, therefore, for the individual user who has only one battery to charge, the vibrating type of rectifier is to be recommended because of its small size, low cost, simplicity, and cheapness of operation. For the individual user who has several cars with batteries to be charged, and for the small public garage, the small mercury outfit capable of charging three batteries of three cells each in series at a ten ampere rate is best suited, because of its larger output and greater flexibility. For the large garage where the many batteries of various sizes and types are to be changed the more elaborate mercury rectifier shown in Fig. 6 has been especially designed. It can be used on either line voltage, has an extremely wide range of cells, and can be adjusted for either tapering or quite flat charging rates. Some one of these three types of outfits will suit almost any set of conditions that may occur.

Immersion Heaters

FOR WATER, LIQUIDS, OR SEMI-LIQUIDS

E. F. Carpenter

THIS ARTICLE PRESENTS notes from several sources which it is deemed will be of interest to those desiring information as to the application of electric heat to the heating of water and the many oils, liquids and semi-liquids used in a wide variety of manufacturing processes. It presents specific facts, examples, tables and commercial comments.

ELECTRIC HEATERS for the heating of water and various liquids should preferably be of the immersion type, for the reason that when the heater is completely immersed it gives practically all its heat to the liquid and is very nearly 100 percent efficient, the only heat loss being the heat given to the air by the liquid itself. For this reason what are called immersion discs, Fig. 1, or immersion bayonet heaters, Fig. 2 should be used. Disc heaters are constructed of a slotted ribbon heating element wound on a mica sheet with mica sheets to insulate it from the metal disc casing. The leads are continuations of the ribbon element, mica insulated, and connected to terminals in the handle where the cord is also attached. Bayonet heater elements are also of the slotted ribbon type, mica insulated and assembled in long seamless copper tubes or bayonets. All joints and seams are brazed both on the disc and bayonet types so that they will be no more subject to damage by heat than the sheet metal itself. These types are of the simplest form. All odd and freak shapes and sizes should be avoided, inasmuch as in most cases they are both mechanically and electrically weak.

These heaters have their widest application in the heating of water. The great majority of water heating applications are easily taken care of by standard heaters now being manufactured. However, every water heating application requires careful consideration covering a great many points. The data necessary is indicated in the following list, not only

for water heating, but for the heating of most other liquids used in the various manufacturing processes:—

1—Temperatures to be maintained.
2—Time allowed to heat up to this temperature.
3—Amount of water or liquid to be heated.
4—If any movement or flow during cycle of operation, in what amount.

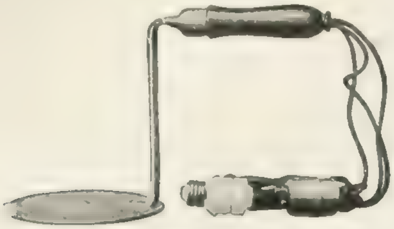

FIG. 1—IMMERSION DISC HEATER

5—Material of containing vessel, weight of same, whether of polished nickel or copper finish, galvanized surface, and whether insulated from radiation losses or not. The kind of insulation and thickness, etc.
6—Sketch showing size and shape of vessel and space allowed for heater.
7—If other than water, chemical characteristics, specific gravity, specific heat, and any other characteristic that may influence the input required.
8—If it is desired to maintain approximately a given temperature the allowable limits of variation should be considered.
9—The temperature of the liquid as it comes to the heater should be taken, and the lowest temperature of the air surrounding the containing vessel should also be taken.
10—In general, all operating conditions, special characteristics or unusual features of the proposed installation should be carefully noted as it may act to affect temperatures or satisfactory operation.
11—The voltage of the circuit is important for the reason that it is preferable not to go above 250 volts.

In most cases, especially of the larger installations, losses by radiation from the surface of the containing vessel should be given consideration, and if these losses are very large the vessel should be thoroughly lagged with at least two inches of good heat insulation material. It should be noted that in all cases of the larger installations special circuits will have to be run and meters installed due to the higher current capacity required.

The disc type immersion heater, which gives a range of from 125 to 1 100 watts, will be found satisfactory for practically all the smaller applications, such as are to be found in restaurants, barber shops, soda

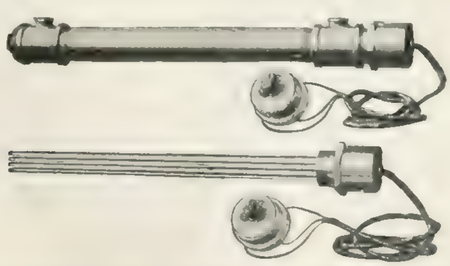

FIG. 2—BAYONET TYPE HEATER WITH AND WITHOUT CASING

fountains, offices, kitchens, chemical laboratories, candy factories, theatrical dressing rooms, dental parlors and laboratories, hospitals, and surgical operating rooms. This heater can also be used for many detail applications in manufacturing processes requiring the heating of small amounts of water, paraffine, oils, glues, waxes, inks, glucose, belt dressings, low melting solders, and the like.

FIG. 3—DETAIL VIEW OF GLUE POT HEATED BY AN IMMERSION DISC HEATER

The bayonet type immersion heater has a very wide field, being applicable to many uses similar to those mentioned above when carried out on a larger

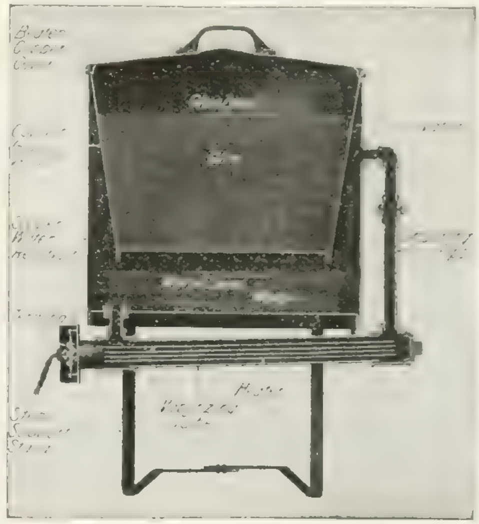

FIG. 4—SECTION OF LARGE GLUE POT WITH BAYONET HEATER

scale. It is the most efficient and satisfactory heater yet produced for the heating of the larger hot water and steam sterilizers for hospital use. When applied

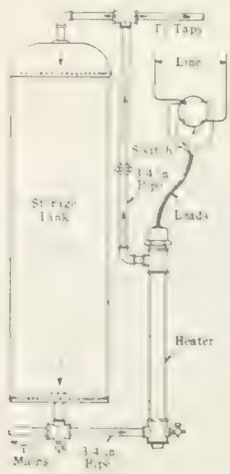

FIG. 5—SCHEMATIC DIAGRAM OF CORRECT HEATER INSTALLATION

to the common hot water or storage tanks to be found in the home, ranging from 20 to 40 gallons capacity,

degrees in three hours time, the efficiency being estimated at 85%.

$$\frac{146 \times 100 \text{ gal.} \times 100 \text{ deg.}}{180 \times 0.85} \quad \frac{1\,460\,000}{153} =$$

9 550 watts, approximately. Or given the watts as 10 500, other data the same as above, and required to show the time, will work out,

$$\frac{146 \times 100 \text{ gal.} \times 100 \text{ deg.}}{10\,500 \times .85} = 164 \text{ minutes, or 2 hours and 44}$$

min., approximately.

Another formula which will be of considerable use with liquids of other characteristics than water will be

$$W = \frac{w \times a \times T \times 60}{3.41 \times m}$$

Where W = theoretical input of heater req. in watts.
Where a = specific heat of liquid to be heated.
Where T = temperature increase, degrees F.
Where w = weight of liquid in pounds.
Where m = minutes required to accomplish change in temperature.

The efficiency of the installation has not been allowed for in this formula and must be taken care of as a separate calculation.

The bayonet heater should be so installed in the system that cold water is drawn from the bottom of the tank through the heater and returned to the top of the tank heated to nearly the maximum required temperature, as shown in Fig. 5, so that hot water may be drawn from the top of the tank shortly after the heater switch is turned on. In cases where this method is not required or other reasons make it advisable, the bayonet heater may be inserted through the bottom or side of the tank and so be immersed in the whole mass of the liquid, which will be raised as a whole to the required temperature.

Where the cost of current is low, say from two cents down to 0.5 cent per kw-hr, electricity can compete with other forms of heat, and there is an immense field for these types of heaters as yet untouched. Central stations which are in a position to make low rates for this class of electric heating, especially the hydro-electric plants in the Rocky Mountain region and on the Pacific Coast are beginning to appreciate the value of this load on their lines in giving them a better load factor, and are making every effort to promote progress along these lines.

Outdoor Switch and Circuit Breaker Apparatus

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Westinghouse Electric & Mfg. Company

THERE HAS BEEN such an unusual amount of development and application of out-door switching apparatus in the last few years, that only those who are in close touch with current progress in these lines can keep informed as to the designs available for the different voltages and other operating conditions. It is with the idea of outlining present conditions in the field of out-door switch and circuit breaker apparatus that the present article has been prepared.

The requirements for outdoor service are extremely varied. The apparatus which has been developed includes the air-type and the oil-type switches, the air-type fuses and oil-type circuit breakers. The air-type switches are made in several current capacities and in all voltages up to 165 000. The oil-type switch or non-automatic oil circuit breaker is made for the same range of service as the air-type switch, up to 165 000 volts. The air-type fuses of the "Bomb" type are made in capacities up to 100 amperes and 25 000 volts. Oil circuit breaking apparatus is available in a variety of types and sizes for various methods of mounting in capacities up to 165 000 volts and to meet any present plant capacity.

In Figs. 1, 2 and 3 are shown representative automatic oil circuit breakers for the higher range of transmission voltages from 44 000 to 132 000 volts, for either hand or electrical operation. These circuit breakers are of the floor mounting type and they therefore require practically no supporting structure when mounted on the ground. They are equipped with what is known as the condenser type terminal bushing, as illustrated in Fig. 4, which shows an outdoor terminal for a 165 000 volt circuit breaker or transformer. The highest voltage on which outdoor apparatus is now being operated is approximately 130 000 volts, so that no 165 000 volt apparatus of the outdoor type is yet in service at full voltage. The detail construction of the switch members and the terminal arrangement in this type of circuit breaker are shown in Fig. 5. The contacts are of the triple butt type, that is, they consist of three cylindrical plunger type contacts, two of which are supported to make contact after the third, which is known as the arcing tip. The two short contacts are known as the main contacts and have a very long life on account of the absence of any arcing thereon. The capacity of this type of circuit breaker is usually not required to be greater than 300 amperes. This type of contact is unusually substantial and requires the least inspection and maintenance, which is an essential feature in outdoor service. The stationary contact members are mounted on the lower end of the terminal bushings, and are of such shape as to reduce the intensity of the static field. It will also be noted that the contact details on the moving cross-bar are covered with appropriate static shields, elliptical in shape. These enclose the contact shunts and nuts which have a great many sharp edges and would cause highly concentrated static stresses, if not appropriately shielded. A third static shield encloses the adjusting details at the center of the contact cross-bar. This covers the sharp edges presented by the nuts and studs which form the adjusting means in properly locating the relation of the moving contact to its supporting rod and the stationary contacts.

On this class of circuit breakers, the contact op-

erating rod is made of "micarta" instead of wood on account of its greater mechanical strength and uniformity of structure, as well as its non-hygroscopic qualities. Immediately above the stationary contact

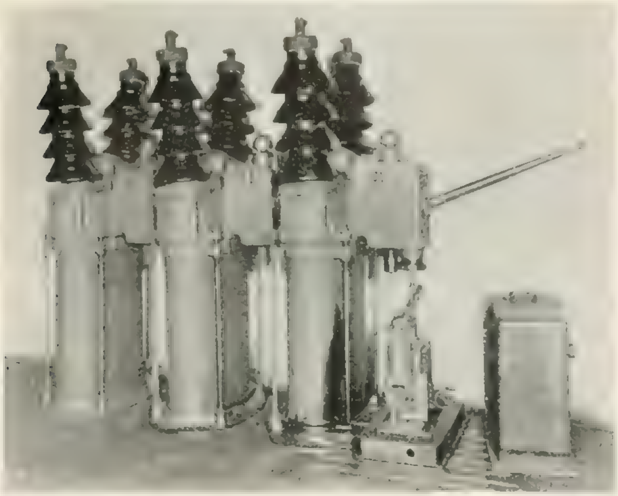


FIG. 1—A 44 000 VOLT, THREE-POLE ELECTRICALLY-OPERATED CIRCUIT BREAKER

Cover removed from operating mechanism.

members is the porcelain shield enclosing the lower or oil end of the condenser terminal bushing. This serves the purpose of preventing the settlement of dust and carbonized sediment usually present in the oil, on the terminal bushing. It has been found in practice that the static field present around a terminal bushing, in high voltage service, attracts all dust and dirt particles from the oil, so that they lodge on the surface of the bushing and impair its insulation. These porcelain shields prevent this lodgment directly on the bush-

FIG. 2—A 77 000 VOLT, THREE-POLE ELECTRICALLY-OPERATED CIRCUIT BREAKER

ing and it is found the agitation of the oil keeps the porcelain itself clean, because the sediment does not adhere to the glazed surface.

Immediately above the porcelain shield, in the circuit breaker in Fig. 5, are shown the bushing-type current transformers concentric with the bushing and mounted in supporting cases, suspended from the mechanism casting or top of the circuit breaker. These

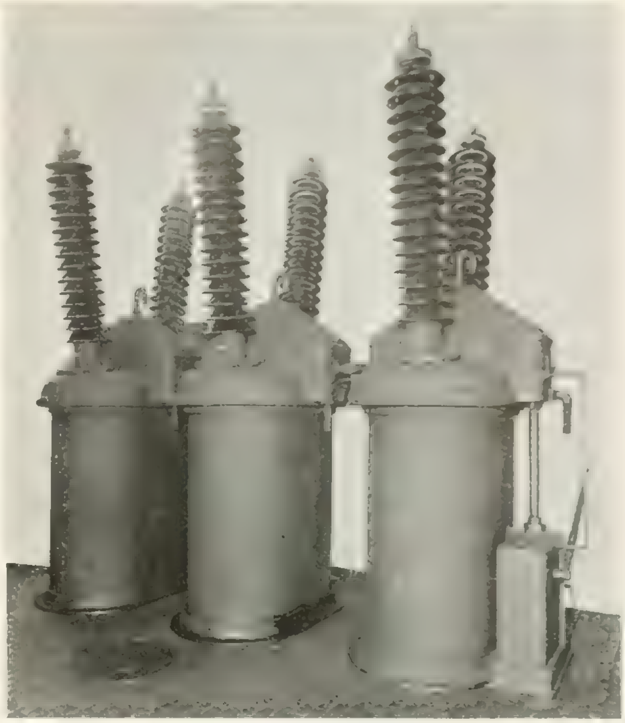


FIG. 3—A 132 000 VOLT, THREE-POLE ELECTRICALLY-OPERATED CIRCUIT BREAKER

supply the low voltage current for operating meters or overload trip coils and relays where the circuit breaker is of the automatic type.

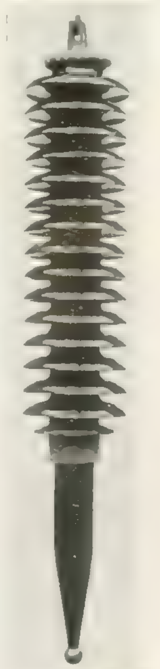


FIG. 4—A 150 000 VOLT OUTDOOR-TYPE CONDENSER TERMINAL

The outer, or air ends of the terminal bushings are provided with porcelain rain shields and vary in diameter and number with the varied voltage. These enclose the condenser type bushing and form a tube around it, which is filled with an appropriate insulating gum to keep out all moisture. All of the operating mechanism is entirely enclosed to protect it from rain, sleet and other common weather conditions. This type of circuit breaker has been in successful use on service as high as 100 000 volts throughout several severe winters, even when almost completely encased in snow and ice.

Figs. 6, 7 and 8 illustrate several types and sizes of outdoor oil circuit breakers for service from 750 to 33 000 volts with intermediate voltages of 2 500, 4 500, 7 500, 15 000 and 22 000 volts. This general type of circuit breaker for voltages up to 15 000 volts is usually intended for pole mounting in the same general manner as the distributing transformer. They are usually equipped with series trip coils connected directly in

the main circuit and mounted in the oil to provide adequate insulation and protection from moisture. The overload tripping feature is usually provided with an adjustable inverse time element dashpot, also

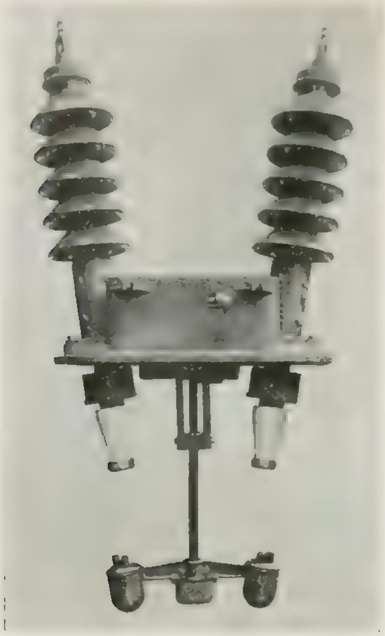


FIG. 5—ONE POLE OF A 55 000 VOLT CIRCUIT BREAKER REMOVED FROM TANK
Showing triple butt type of contact.

enclosed in the oil tank, as it is undesirable to have a pole mounting circuit breaker open the circuit except under sustained overload conditions. The form of contact details, their insulating supports, the trip coils, and dash pot used in this general type of circuit breaker are illustrated in Fig. 9. This shows a subway type circuit breaker, with the tank and cover re-

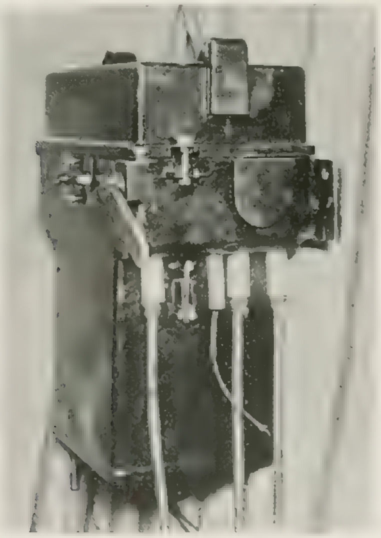


FIG. 6—A 2 500 VOLT, 200 AMPERE, HAND-OPERATED CIRCUIT BREAKER
Small leads connecting to current tranformer for automatic trip.

moved, rated at 4 500 volts, 200 amperes. The outdoor type of circuit breaker for voltages of 15 000 and below is usually supplied with a single tank enclosing all poles. The form for voltages above 15 000 up to approximately 22 000 volts is of the type having an individual rectangular tank per pole as illustrated in Fig.

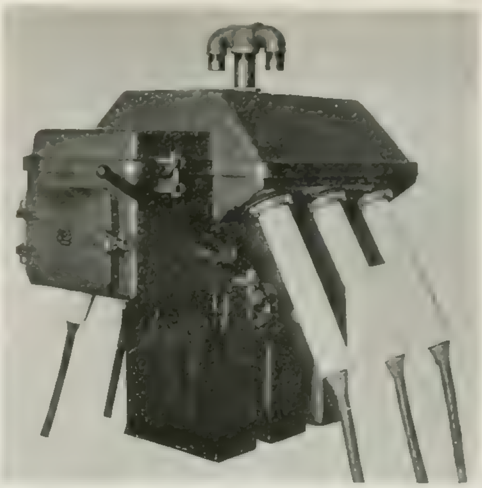


FIG. 7—AN 11 000 TO 22 000 HAND-OPERATED CIRCUIT BREAKER

7. This type of circuit breaker is usually provided with bushing type transformers supplying secondary

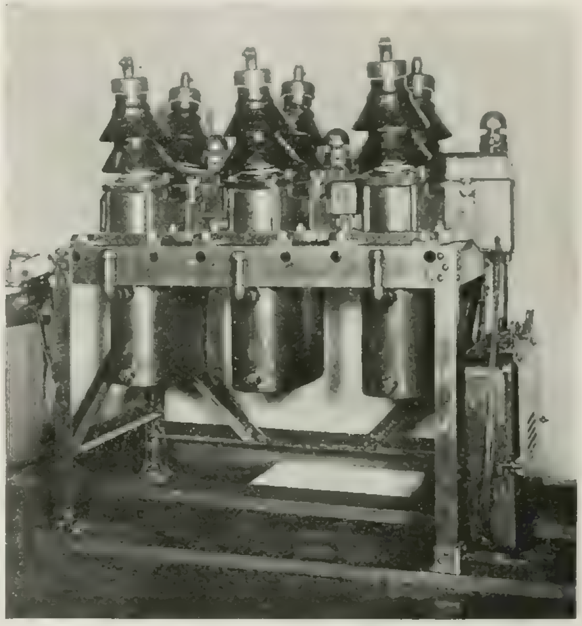


FIG. 8—A 33 000 VOLT BRIDGE TYPE AUTOMATIC CIRCUIT BREAKER
Developed in connection with single-phase electrification of the New York, New Haven and Hartford Railroad for the automatic separting of feeder sections.

trip coils rather than direct series trip coils. The several designs illustrated are of the hand-operated type,

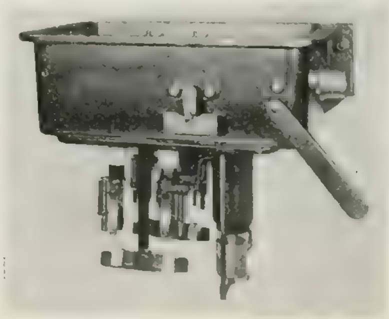
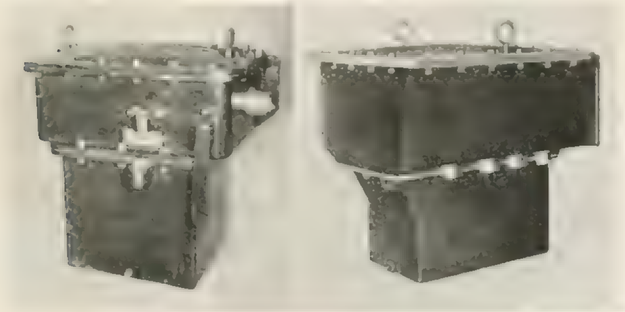


FIG. 9—VIEW SHOWING INTERNAL CONSTRUCTION OF GENERAL TYPE OF CIRCUIT BREAKER SHOWN IN FIGS. 10 AND 11

which is usual, as this size of circuit breaker is generally used in the distributing system and not as a part

of an outdoor sub-station requiring an attendant, or remote electrical operation. The 33 000 volt design, shown in Fig. 8, consisting of three elliptical tank units mounted on an angle iron frame, is electrically operated. At this voltage the general designs and

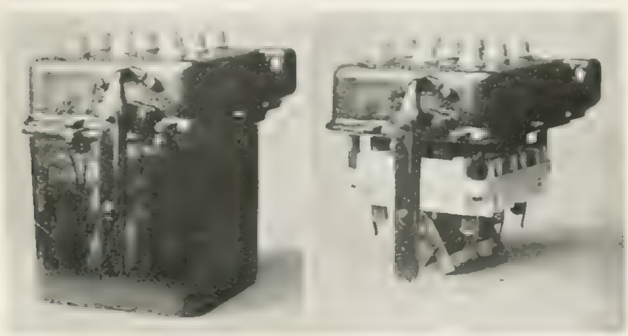


FIGS. 10 AND 11—HAND AND ELECTRICALLY-OPERATED SUBWAY TYPE CIRCUIT BREAKERS

service requirements change, and it will be noted that the design tends to a similarity with the higher voltage designs shown in Figs. 1 to 3. The contact details of the 22 000 and 33 000 volts circuit breakers illustrated are of the double butt form similar to circuit breakers for higher voltage. In the double butt form, one large

FIG. 12—HAND-OPERATED, DOUBLE-THROW POLE TYPE OIL SWITCH

cylindrical type contact is used for the main contact and a small cylindrical contact, longer than the main contact, is used as the arcing tip. Usual conducting requirements are 200 amperes or below in this service and several hundred of this type of circuit breaker, both hand and electrically operated, have been



FIGS. 13 AND 14—A 4 500 VOLT, DOUBLE-THROW SUBWAY TYPE OIL SWITCH, WITH AND WITHOUT CASE

in use for several years, particularly as sectionalizing circuit breakers mounted outdoors on single-phase railway systems.

Figs. 10 and 11 illustrate subway forms of automatic circuit breakers, oil type, hand and electrically operated, respectively. Fig. 9 is an interior view of Fig. 10 and illustrates the form of contacts and insulating trip mechanism details for this general type. The contacts are of the wedge and finger type with

FIG. 15—A 2 500 VOLT [illegible]

plunger type arcing tips to remove the arcing from the wedge contacts. The electrically-operated mechanism is enclosed in the upper part of the case of Fig. 11. This form can be totally submerged without injury

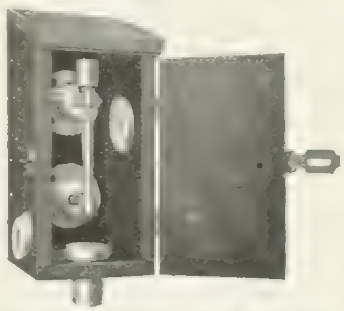


FIG. 16—A 7 500 VOLT OUTDOOR TYPE ENCLOSED FUSE [illegible]

and is provided with bushings for lead covered cables.

Distinct from the general design of outdoor oil circuit breakers are the outdoor and subway oil switches, illustrated by Figs. 12 and 13. These show

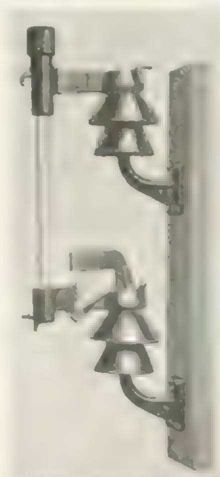


FIG. 17—A 22 000 VOLT OUTDOOR FUSE AND AIR BREAK DISCONNECTING SWITCH

double-throw, three-pole, 4 500 volt switches of 200 amperes capacity and have the knife blade and jaw form of contact similar to the ordinary knife switch, mounted on porcelain supports and having vertical barriers between the contact details of the several

the main circuit and mounted in the oil to provide adequate insulation and protection from moisture. The overload tripping feature is usually provided with an adjustable inverse time element dashpot, also

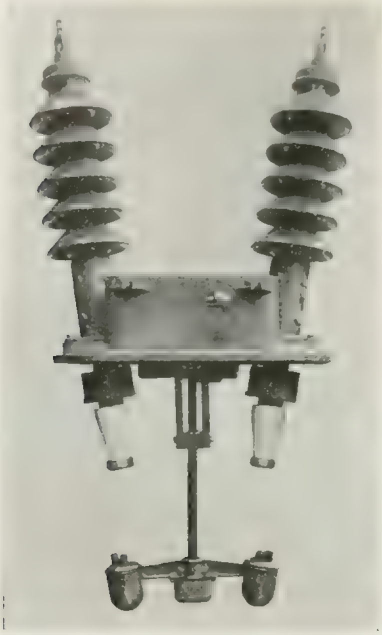


FIG. 5—ONE POLE OF A 55 000 VOLT CIRCUIT BREAKER REMOVED FROM TANK
Showing triple butt type of contact.

enclosed in the oil tank, as it is undesirable to have a pole mounting circuit breaker open the circuit except under sustained overload conditions. The form of contact details, their insulating supports, the trip coils, and dash pot used in this general type of circuit breaker are illustrated in Fig. 9. This shows a subway type circuit breaker, with the tank and cover re-

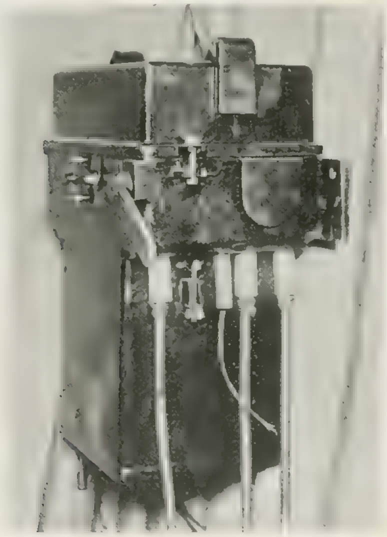


FIG. 6—A 2 500 VOLT, 200 AMPERE, HAND-OPERATED CIRCUIT BREAKER
Small leads connecting to current tranformer for automatic trip.

moved, rated at 4 500 volts, 200 amperes. The outdoor type of circuit breaker for voltages of 15 000 and below is usually supplied with a single tank enclosing all poles. The form for voltages above 15 000 up to approximately 22 000 volts is of the type having an individual rectangular tank per pole as illustrated in Fig.

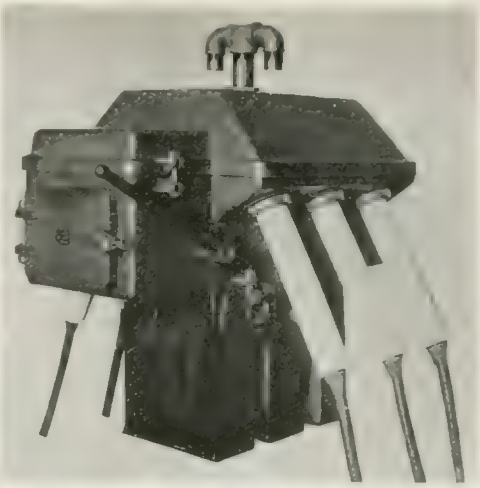


FIG. 7—AN 11 000 TO 22 000 HAND-OPERATED CIRCUIT BREAKER

7. This type of circuit breaker is usually provided with bushing type transformers supplying secondary

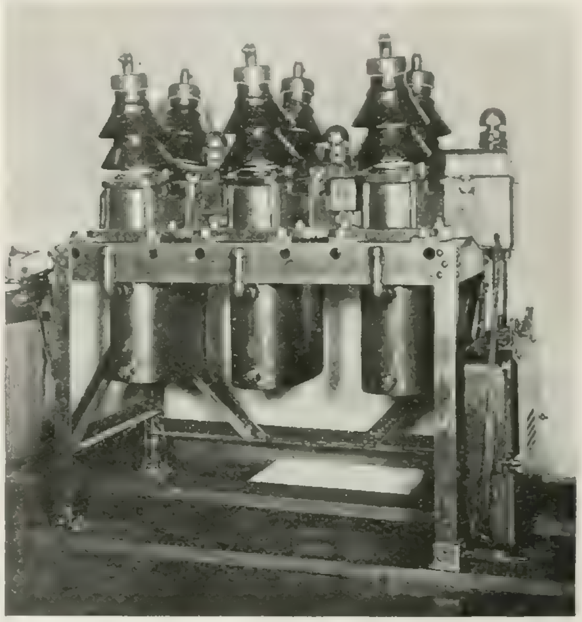


FIG. 8—A 33 000 VOLT BRIDGE TYPE AUTOMATIC CIRCUIT BREAKER
Developed in connection with single-phase electrification of the New York, New Haven and Hartford Railroad for the automatic separting of feeder sections.

trip coils rather than direct series trip coils. The several designs illustrated are of the hand-operated type,

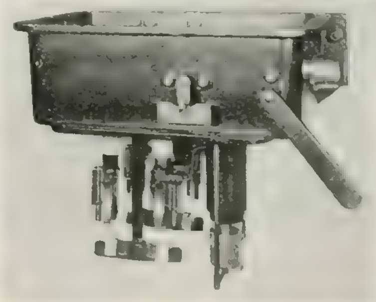


FIG. 9—VIEW SHOWING INTERNAL CONSTRUCTION OF GENERAL TYPE OF CIRCUIT BREAKER SHOWN IN FIGS. 10 AND 11

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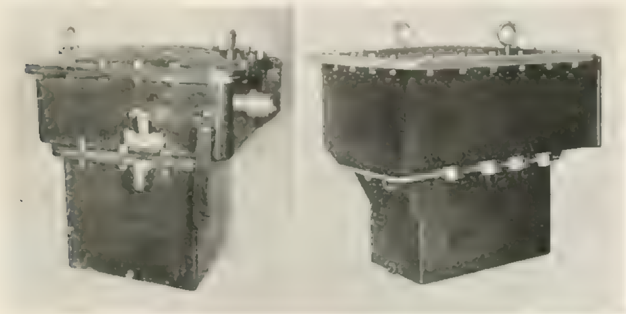

FIGS. 10 AND 11—HAND AND ELECTRICALLY OPERATED SUBWAY TYPE CIRCUIT BREAKERS

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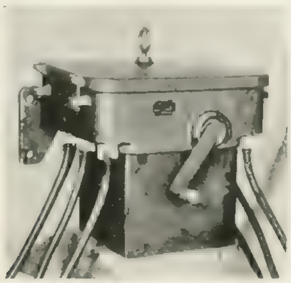
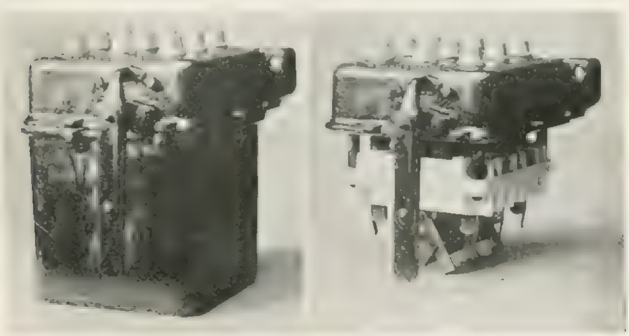


FIG. 12—HAND-OPERATED, DOUBLE-THROW POLE TYPE OIL SWITCH

cylindrical type contact is used for the main contact and a small cylindrical contact, longer than the main contact, is used as the arcing tip. Usual conducting requirements are 200 amperes or below in this service and several hundred of this type of circuit breaker, both hand and electrically operated, have been



FIGS. 13 AND 14—A 4 500 VOLT, DOUBLE-THROW SUBWAY TYPE OIL SWITCH, WITH AND WITHOUT CASE

in use for several years, particularly as sectionalizing circuit breakers mounted outdoors on single-phase railway systems.

Figs. 10 and 11 illustrate subway forms of automatic circuit breakers, oil type, hand and electrically operated, respectively. Fig. 9 is an interior view of Fig. 10 and illustrates the form of contacts and insulating trip mechanism details for this general type. The contacts are of the wedge and finger type with

FIG. 15—A 2 500 VOLT OUTDOOR TYPE [illegible]

plunger type arcing tips to remove the arcing from the wedge contacts. The electrically-operated mechanism is enclosed in the upper part of the case of Fig. 11. This form can be totally submerged without injury

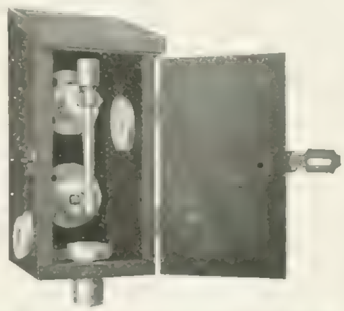


FIG. 16—A 7 500 VOLT OUTDOOR TYPE ENCLOSED FUSE BLOCK

and is provided with bushings for lead covered cables.

Distinct from the general design of outdoor oil circuit breakers are the outdoor and subway oil switches, illustrated by Figs. 12 and 13. These show

FIG. 17—A 22 000 VOLT OUTDOOR FUSE AND AIR BRAKE DISCONNECTING SWITCH

double-throw, three-pole, 4 500 volt switches of 200 amperes capacity and have the knife blade and jaw form of contact similar to the ordinary knife switch, mounted on porcelain supports and having vertical barriers between the contact details of the several

poles. Fig. 14 shows the subway type switch with tank removed, illustrating the arrangement of these details. Arcing tips of the finger type are used with this form of contact.

Outdoor mounting fuse devices for 2 500 volt, 7 500 volt and 25 000 volt service are shown in Figs.

FIG. 18—A 22 000 VOLT SELECTOR TYPE DOUBLE-THROW OUTDOOR DISCONNECTING SWITCH

15, 16 and 17. The smaller block is of the type usually used for fusing the primaries of 2 200 volt distributing transformers. The box shown in Fig. 16 has the bomb type of tubular form of fuse chamber of the indoor type, mounted in a wood box for outdoor protection. The larger or 25 000 volt form shown is also of the bomb type with the insulating tube chamber enclosed in a porcelain tube, and therefore adapted to outdoor mounting. This form of fuse device can also be used as a disconnecting switch, as it is provided with jaw terminals, and a hinging arrangement so that

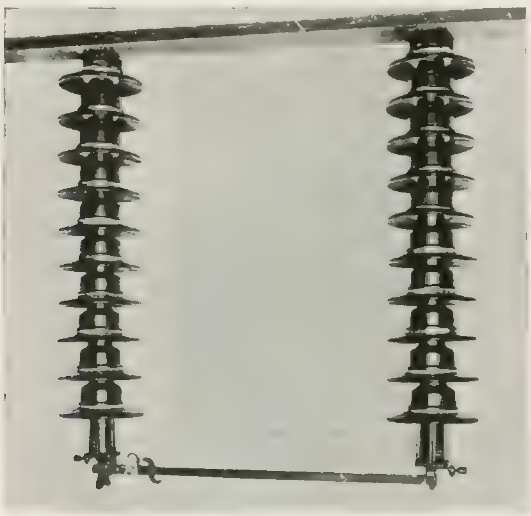


FIG. 19—A 150 000 VOLT SINGLE-THROW OUTDOOR DISCONNECTING SWITCH

Equipped with sleet shields and static protector.

it can be removed with a special pole of wood. The smaller bomb type fuse in the wood box can also be used as a disconnecting switch by the use of appropriate insulating removing tongs. The 2 200 volt porcelain plug type has the plug made removable for refusing and disconnecting purposes.

In Figs. 18 and 19 are shown representative types of outdoor inverted, or "under hung" disconnecting switches for 13 000 to 150 000 volt service. The 22 000 volt switch shown in Fig. 18 is provided with a sleet shield over the break jaw and latch details. All of these switches are provided with a latch to prevent the opening of the switch except when operated by the hook stick. When this hook stick is placed in the eye on the blade, it first operates the latch and then the switch blade with the same pull. The 150 000 volt double throw type shown in Fig. 19 is provided with a unit type insulator of the "Quaker hat" type. These units are individually replaceable.

In Fig. 20 is shown a drawing of a mechanical remote control 100 000 volt disconnecting switch. This is shown hand-operated, single-pole, but can be manufactured either hand or electrically operated, and for 1, 2, 3 or 4 poles. It is equipped with the unit type pillar insulator, and in common with the unit type designs above mentioned, the pillars can be

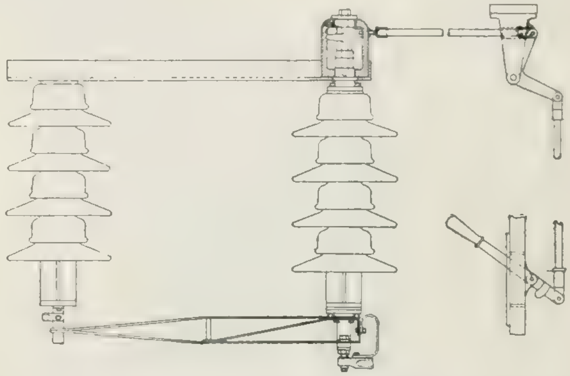


FIG. 20—OUTDOOR TYPE OF REMOTE MECHANICAL CONTROL HIGH VOLTAGE DISCONNECTING SWITCH

mounted with either end attached to the base. This permits of the contacts and pillars being mounted either downward or upward with reference to the base, and makes a very flexible design to meet the various operating conditions. When single-pole units only are required for operation by a hook stick, it is usually desirable to have the blade below the base, if no arc is to be broken. When the charging current of a line or the magnetizing current of a transformer is to be broken, it is preferable to mount the blade above the base to prevent the arc striking to the base or ground. With the rotary type of pillar, as shown in Fig. 20, the blade moves on a horizontal plane and can be provided with horns to assist in handling the arc. In this case, the blade is always mounted above the base. The "Quaker hat" type of insulating unit with the metal fittings adapted thereto, are capable of withstanding comparatively large mechanical stresses in practically any direction, such as bending, tension, torsion or compression when made up in pillars as shown. The porcelain sections coming under stress are in compression in practically every case.

The Development of a Pole Hoisting Derrick

W. A. LaDue
Division Superintendent
Public Service Electric Company, Jersey City, N. J.

DEPARTMENTS RESPONSIBLE for outside plant construction and operating men in general will be interested in the following article describing apparatus which meets a long-felt need for use in the erection of poles from 35 to 65 feet in length, and which is applicable not only on highways but can also be used with decided efficiency in the construction of heavy pole lines on private rights of way and across country where no highways exist.

IN the year 1913-14, a transmission line 40 miles in length was constructed between Trenton and Camden, N. J., by the Public Service Electric Company, by the aid of the special pole hoisting derrick illustrated and described herein. This line consists of Class A chestnut poles, 45 to 65 feet in length, with galvanized iron cross-arms and steel pins, for operating at 13 200 volts, three phase, 60 cycles. About 25 percent of this line is located in open fields and the balance on the highway. The derrick was particularly useful in the cross-country work, where rapid progress was made, and on the highway as many as forty-five 50 foot poles were erected in a single working day of nine hours.

FIG. 1—POLE-HOISTING DERRICK WITH BOOM VERTICAL, IN READINESS TO HOIST A POLE INTO POSITION

FIG. 2—A 45 FT. POLE LIFTED TO POSITION WITHOUT THE USE OF A BACK GUY

Since erecting poles in a territory of this kind by the use of a gin pole or raising them with pikes would be a very expensive and long drawn out job, it was necessary that some apparatus be designed to overcome these obstacles, and the derrick, which is the subject of this article, has met our requirements in every sense and was the direct means of saving from one to three dollars per pole erected.

Another innovation employed was the substitution of motor trucks for horses in the distribution of poles, and the employment of large pairs of wheels, beneath the axles of which several poles were swung for transportation. Horses may be used in connection with the derrick for hoisting the poles, but the motor trucks with their requisite gear make the work still more rapid and more satisfactory.

The accompanying illustrations show the construction details of the derrick and also some views

of the apparatus in operation. The principal feature or secret of the flexibility of this derrick is in a universal joint at the top of the stationary frame work, which permits the boom or mast to be swung into a position parallel to the highway or into a vertical position and also transverse to the platform. This transverse motion allows the boom to be inclined so that the upper end swings over the hole into which the pole is to be set. In order that the boom may be operated quickly and with perfect safety, two guide troughs are built at right-angles on the platform, which entirely eliminate any swaying or playing of the boom; and bolts are provided through these guides so that the boom can be stopped at any angle and rigidly secured. The platform frame-work and all wood used in the outfit consist of well seasoned oak and can be built by any wagon manufacturer or handy carpenter.

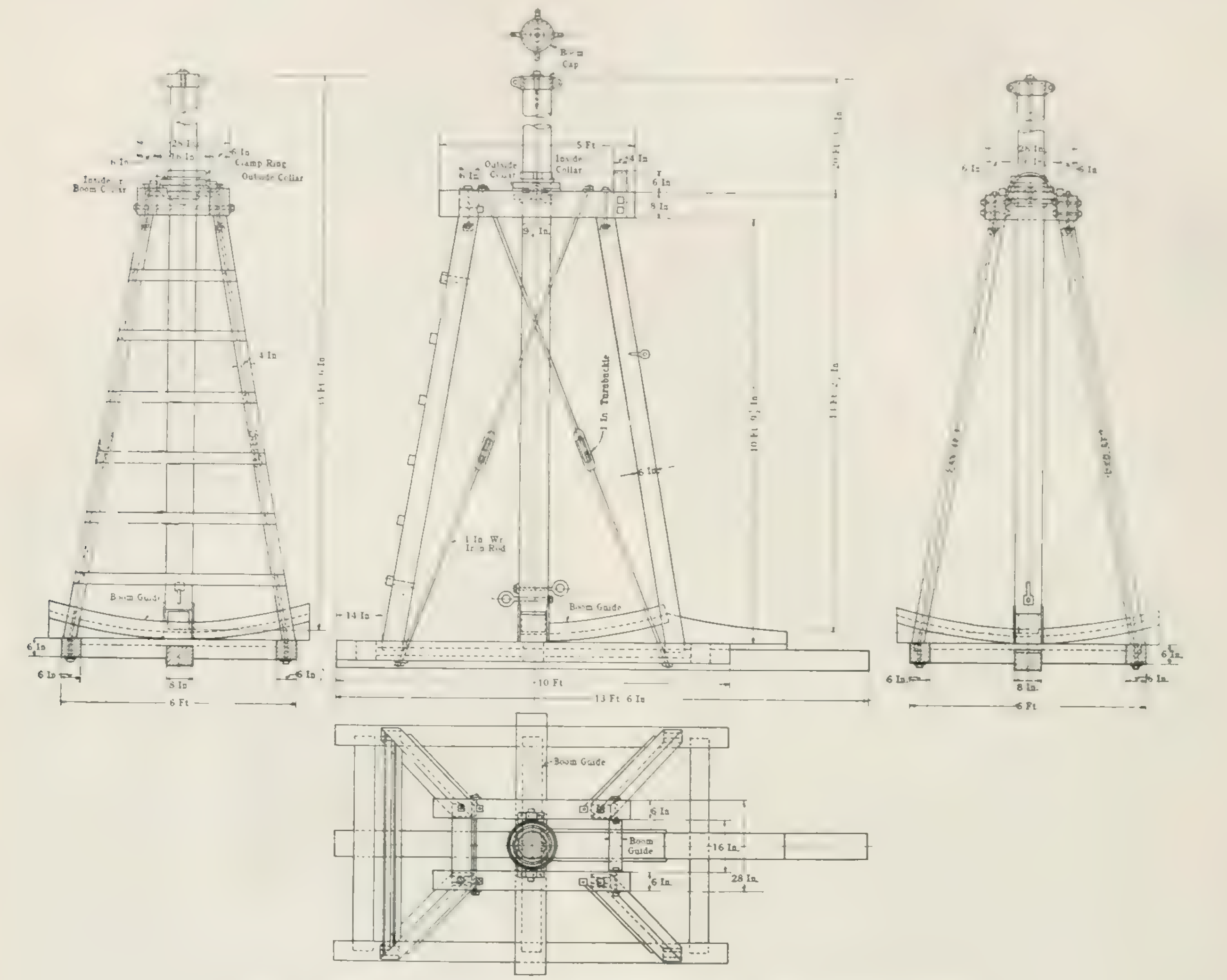


FIG. 3—WORKING DIAGRAM FOR CONSTRUCTING THE POLE-HOISTING DERRICK

In Fig. 2 the derrick is shown with a Class *A*, 45 foot pole hoisted without the use of any back guy on the derrick, but provision is made for the use of a back guy, which makes the derrick absolutely secure at all times for extra heavy lifts. The center guy gives a truss effect and is applied for stiffening purposes only, and the portable guy can be fastened anywhere along the road as the derrick is moved. When the boom is reversed for operation on the opposite side of the road,

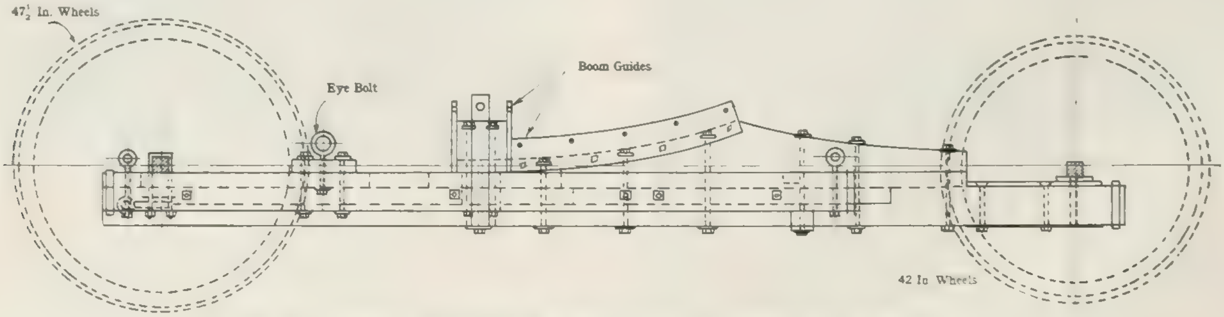


FIG. 4—ASSEMBLY DIAGRAM OF DERRICK BASE, PLATFORM AND BOOM GUIDES

the guys are also changed. The necessary labor to operate this derrick is a team, driver and three men.

An interesting feature is the ease with which the derrick handled poles in locations where trees were very thick and poles were hoisted through the branches, taking branches with it and even breaking off heavy limbs with no appreciable hindrance or dangerous strain on the derrick.

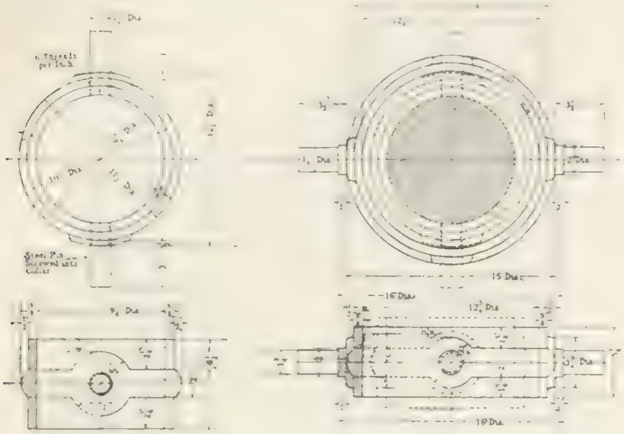


FIG. 5—DETAIL DIAGRAM OF INSIDE BOOM COLLAR AT LEFT AND OF OUTSIDE COLLAR AT RIGHT

The inside boom collar is shown in position at the right by dotted lines.

The tire width of the wheels is six inches, which is good for ordinary country roads, can be used in cities, and is of special importance in fields and on private right of way where the soil is soft. In several instances the derrick was moved 20, 25 and 30 feet, after a pole had been hoisted, in order to get to a hole where the pole was to be set, without any danger of toppling over. All poles were hoisted with cross-arms applied and in many instances 6 to 12 arms were bolted to the pole tops, making an added weight of 80 pounds per arm.

The general results obtained from this derrick have greatly exceeded our expectations. The cost is comparatively small, if its advantages are to be considered, and a great many uses can be made of it aside

FIG. 6—A VIEW OF THE DERRICK WITH THE BOOM IN THE HORIZONTAL POSITION FOR TRAVEL THROUGH STREETS AND HIGHWAYS

from setting poles. It is particularly adapted for city streets and for loading and handling of poles, transformers and apparatus in general. As a whole it was found that the time and expense incurred in constructing this special vehicle has well repaid us for the results obtained and it is cheerfully submitted by the designer and builder for the especial benefit of our great industry.

Types and Uses of Graphic Meters

PAUL MACGAHAN

THE increasing necessity for accurate and continuous records of the amount and character of the electrical quantities of interest in connection with the utilization of energy in the industrial field has brought about the development of satisfactory means for obtaining such records. These records have proven of great value in determining the operating efficiency in power houses, recording variations in the power requirements and cost of operation of motor-driven machinery in a wide variety of plants, such as steel and rolling mill drives, machine shops, paper mills, textile mills, wood working plants, etc.; also for obtaining continuous records of the speed of printing presses, looms or other machinery where a constant speed is of importance, or for keeping an automatic record of output of motor-driven machinery. Furthermore, graphic meter records are now being extensively employed by large power companies as a basis for charging for power according to the maximum demand, or peaks lasting a certain length of time; while many factories and large machine shops are using them to advantage in making analyses of the rate of work and the length of time consumed in the various operations.

It is well recognized that indicating instruments are entirely inadequate for the purposes outlined. Their use necessitates the taking of readings at frequent intervals, timing and tabulating them and subsequently drawing the curves which graphically represent the variations indicated. This frequently causes much inconvenience and loss of time to the station attendants. Watthour meters give accurate records of the total energy consumption during a given time, but no idea of the load variation.

The function of graphic meters is to furnish automatically, permanent and continuous records of variations in the energy, voltage, current, etc., of supply circuits; these records having, if necessary, an accuracy fully equal to the momentary readings of the best indicating instruments. The ideal graphic meter

should be rugged, easily understood, connected and adjusted; should operate for a considerable length of time without attention; should be simple, should have a legible record, should not overswing or exaggerate

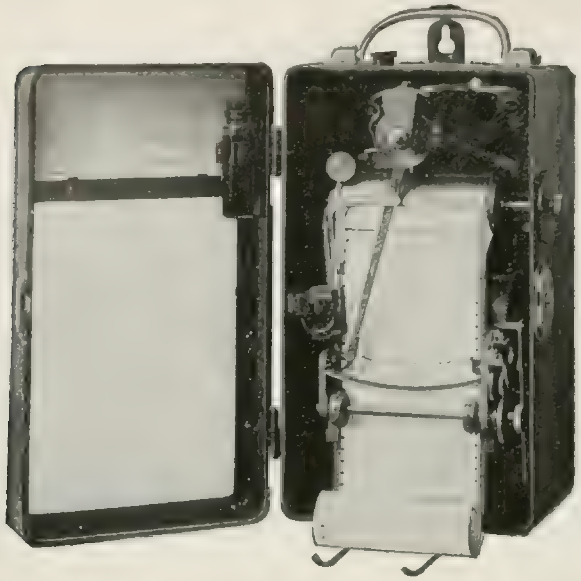


FIG. 1—COMBINED SWITCHBOARD AND PORTABLE TYPE VOLTMETER

variations, and above all should be permanently accurate. Portable meters should, in addition, be light in weight, and adapted to use on various kinds of circuits. Unfortunately, however, the ideal instrument remains yet to be designed, and in selecting an instrument, the characteristics of the service as well as its limitations should be considered carefully.

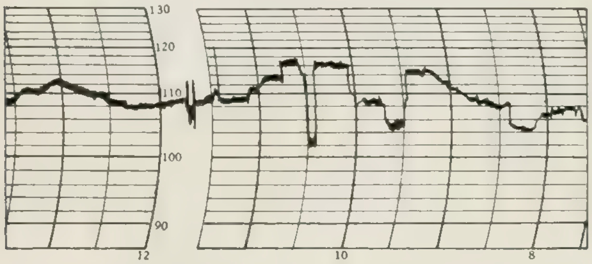


FIG. 2—TYPICAL VOLTAGE CHART TAKEN WITH A METER SUCH AS SHOWN IN FIG. 1

In general, graphic meters may be classified in a manner similar to other electrical instruments, with regard to character of service and to accuracy obtainable, into two groups:—

1—Meters in which simplicity of parts or manipulation, low cost, ruggedness and ready portability or convenience have been the determining factors in the design, at a sacrifice in accuracy.

2—Meters in which accuracy has been made the prime requisite. These meters are either of the semi-portable or switchboard types, are somewhat heavier and more costly and must be handled with a greater degree of care and intelligence, than the first mentioned class.

In graphic instruments, as in all others, the combination of the qualities of high accuracy and simplicity is the ultimate goal of designers, but unfortunately in the graphic meters these two qualities are even more difficult to combine than in indicating meters, owing to the fact that in the graphic meters legibility of record and accuracy in time keeping form additional necessary features. In general, the greater the accuracy desired the more care should be taken in selecting and using any piece of measuring apparatus.

USES

The advantage of using graphic meters lies in the fact that they record electrical measurements automatically and with reference to time. The uses to which such instruments can be applied are innumerable,, but a few of the more common cases are outlined below:—

Station Records—Records of bus-bar voltage, total station load, and loss of loads may be recorded automatically without attention on the part of the station operator other than changing the records periodically. Good lighting service requires a steady voltage; the quality of the light, the life of the incandescent lamps and the degree of satisfaction given to consumers all depend upon careful attention to voltage regulation. Knowledge that such a record is being kept serves as a stimulus to the station operator and a check upon the adjustment of automatic regulators.

Service Records—Even though the station voltage may be kept constant, the e.m.f. of distant points of the line may vary considerably, due to fluctuations of the load, changes in power-factor, adjustment of line drop compensators, or to overloaded transformers or lines. Many companies maintain graphic voltmeters at sub-stations, and in some cases it has been found advisable to set graphic meters at various points of distribution, either in a box on a pole, or near a consumer's meter. A comparison of station and service voltage records provides valuable data for determining line drop and line losses. By mounting an ammeter near a transformer for a week at a time, a continuous record may be obtained of the transformer load, providing valuable indications as to whether the transformer is overloaded or is not working up to capacity. By the use of split type transformers such connections can be made without disturbing the permanent connections of the transformer.

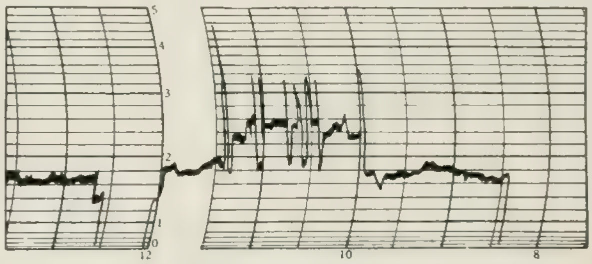


FIG. 3—A CURVE OF KILOWATTS TAKEN WITH A WATTMETER OF THE TYPE SHOWN IN FIG. 1

Customer's Load Curves—A graphic ammeter or wattmeter provides the simplest possible means for obtaining the load curve of the plant of a prospect or customer, from which the maximum demand, load-factor and diversity factor of the connected load can be quickly determined as a basis for rates. For investigating the power conditions in a factory, whether by

a central station solicitor, with a view toward determining whether central station service will be profitable, or by the factory management for the purpose of determining the efficiency and power conditions existing in the plant, the graphic meter is invaluable. The distribution of the load over the factory, the power used for machines, the character of the load, the condition of the cutting tools, the time to complete different operations, and many other similar determinations can be secured by inspection of graphic meter records. Such records also show with what promptness the employees start to work in the morning and also their time of shutting down. It is possible to show just how much power each machine takes, how long it is in use each day, and the cost of power for its operation. Thus they tell when it is necessary to install new machines and when, by suitable changes, further machines can be made to do the required work. By installing the meter in the foreman's or manager's office, the records can be obtained without the knowledge of the workmen, and at the same time furnish exact records of his operations. Efficiency experts are more and more studying the operations of machines in their attempts to increase output, and in such studies the graphic meter is of great assistance. Graphic temperature records are of value in connection with the operation of generating or transforming apparatus.

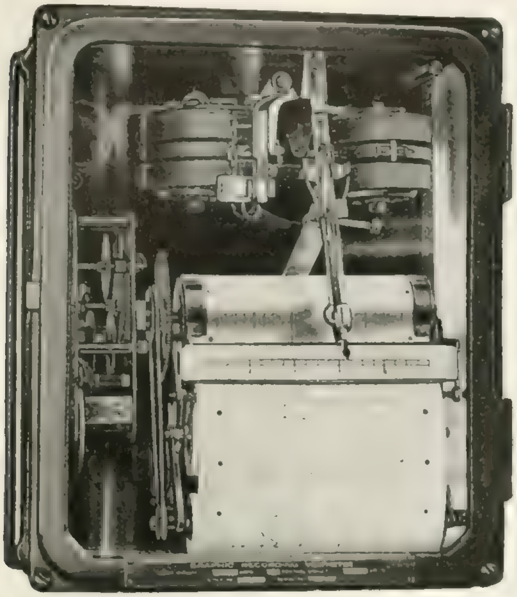


FIG. 4—SWITCHBOARD TYPE GRAPHIC RECORDING VOLTMETER

Central station operators are finding that the uses of the graphic meter are not limited to investigations of prospective plants but during recent years they have come into extensive use in settling disputes with customers relative to power bills. The records often disclose to the customers the use of power at unexpected hours and such uses can be quickly traced when their existence is disclosed. For instance, a graphic record showed to one power user, who had complained of excessive bills, that large quantities of power were used on his premises every hour during the night. Investigation showed that the watchman turned on many of the lights of a large installation in making his rounds; the excess energy thus used explaining a serious discrepancy.

TYPES OF METERS

There are several general types of graphic recording meters in common use, their relative desirability being determined by the characteristics of the service in which they are to be placed.

Circular Dial, 24 hour type—This type of instrument is, in general, portable, rugged and inexpensive. It is easily understood and manipulated and is quite reliable, but as at present constructed is usually lacking in accuracy both as to the character of scale and as to electrical features; the temperature, wave form and frequency errors are considerable in the various kinds tested by the writer, and the construction is such as to be readily affected by external fields. The torque of such instruments is usually low so that the friction of the pen on the paper introduces an appreciable error. Despite these drawbacks, however, the instrument is useful when high accuracy is not essential, and when a 24 hour chart is satisfactory.

Continuous Chart Portable Type—As will be noted by consideration of the list of ordinary uses to which graphic meters are applied, for most purposes a chart which will cover several days' operation continuously without attention is often desirable. This necessitates a chart in continuous or strip form. This type of instrument, as at present made, is usually more accurate than the round dial type, and being of late design, temperature and self-heating errors and errors due to ordinary changes of frequency have been made negligible. The meter shown in Fig. 1 is a combined switchboard and portable form and consists of a sole-

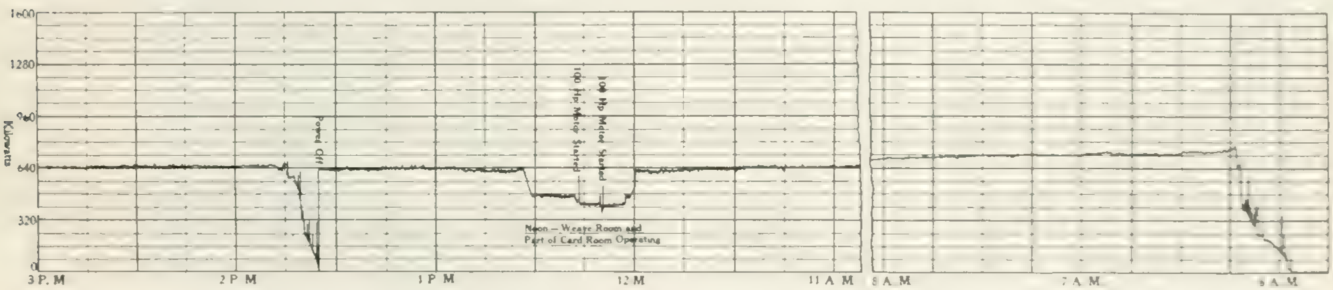


FIG. 5—LOAD CURVE BY GRAPHIC METER
On a five hp induction motor operating a spinning frame.

noid and core, acting directly on an arm that carries the recording pen and a continuous strip of paper is moved uniformly by a high grade eight day, key wound clock mechanism. The friction of the pen on the paper is largely overcome by making the solenoid very powerful in its action. This also allows the control

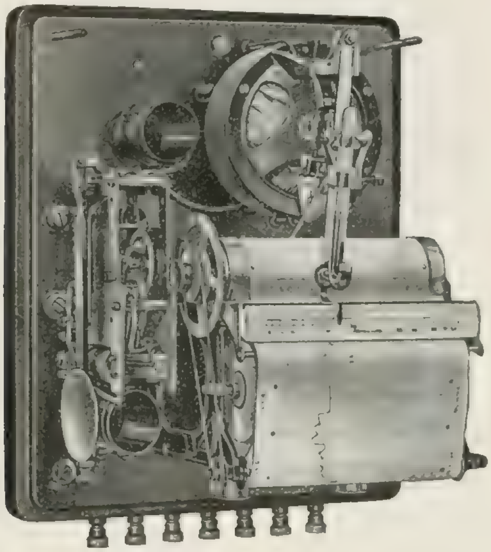


FIG. 6—GRAPHIC RECORDING POWER-FACTOR METER WITH COVER REMOVED

of the movement by a heavy spring, thus reducing the friction error to about one percent of full scale value, which also minimizes inaccuracies due to slight errors in leveling. The energy consumed by the voltmeter, including its external resistor, is 50 watts. The energy consumed by the ammeter is seven watts or less, thus permitting its use with ordinary current transformers. An oil dashpot damps the action of the pointer on fluctuation, but the meter can be operated on fairly steady loads without this. The pen is of the V-point type and a glass ink reservoir which will hold a supply of ink for two weeks of ordinary use is mounted in such a way that a very thin wick, one end of which is in the reservoir and the other in the V-shaped pen, will feed the ink into the pen by capillary action as used. The record paper is driven by a metal drum with pins that engage in perforations in the paper, driven through gearing by a standard eight day clock mechanism of the key-wound type with balance wheel escapement.

Switchboard or very accurate types—In order to increase the accuracy of graphic instruments it is necessary to separate the functions of the measuring element and of the marking device for the reason that the friction introduced by the pen on the paper interferes to a certain extent with the accuracy. This cannot be overcome entirely by increasing the power of the meter coils owing to the electrical errors thereby introduced, especially where current transformers are used. Moreover, increased accuracy also requires a broader and more legible chart which would still further increase the work required of the meter element. Some of the schemes which have been utilizd for overcoming this difficulty are as follows:—

1—Making a continuous photographic record of the position of the pointer or of the movement as in oscillographs.

2—Allowing the pen arm and the pen to swing slightly above the paper and causing it to make a dot at fixed intervals by means of an electro-magnet.

3—Causing a high tension discharge or spark to pass from the pointer through the paper, thus leaving a mark or a perforation at regular intervals.

4—The relay type, in which the meter element serves only to make and break a contact, which in turn controls separate solenoids or motors which deflect the pen.

The first three schemes are of relatively little importance for commercial graphic meters and consequently scheme *4* only will be considered here. The relay type of construction, both in this country and abroad, appears to have solved the problem in a very satisfactory manner. The principle of operation is simple. The meter is separated into two inter-dependent elements, viz., the meter element or measuring coils and the motor element or pen actuating device. These elements are connected by the control spring of the meter. As the function of the meter element is limited to making and breaking contacts, which control the pen actuating element, the meter element need not have any greater torque than that of an indicating meter and should not take any more energy; it

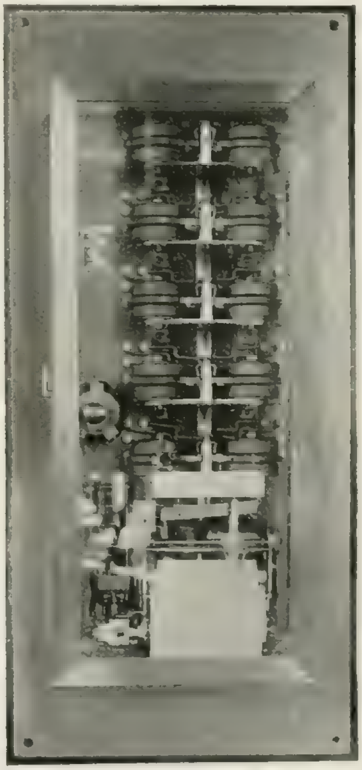


FIG. 7—TOTALIZING METER FOR INTEGRATING THE POWER READING OF SEVERAL NON-SYNCHRONOUS CIRCUITS

can, moreover, be made as accurate electrically as any given indicating meter.

In the form most familiar to the writer, measuring coils of ammeters, voltmeters, frequency meters and wattmeters are astatically arranged on the principle of the Kelvin balance. Each moving coil is

placed between two fixed coils, and the indications depend on the torque between them, the coils being always in the same relative position. This zero reading principle makes the calibration permanent and renders the readings free from the effects of variation in wave form, frequency or power-factor. Temperature, self-heating, external fields, unbalance of system and power factor do not effect the indications, the meters being similar to precision instruments. Because of the fact that the operation is on the Kelvin balance principle, the calibration may be checked up and corrected in a very short time by means of a "self-calibrating weight," which makes it unnecessary to check the readings with a standard meter. This weight is adjusted in the factory to be such as to cause the pen to travel to a fixed point on the scale when no current is flowing through the measuring coils; it thus is equal to the "torque" of the meter.

On the other hand the pen actuating or motor element derives its power from a separate source and can have as much torque as is necessary to control the pen properly. The chart may be made as broad as desirable and in this way an instrument of high accuracy is attainable. The paper feeding roll is turned by a high-grade self-winding pendulum type clock which can be provided with a synchronizing attachment for connection to the Western Union time service wires, or to a synchronizing master clock.

By means of several meter elements all actuating a single set of contacts a totalizing meter can be made which will integrate the power in several non-synchronously operated circuits. Relay type meters are made by but few manufacturers owing to the great amount of research, development and skill required in designing and constructing their contacts and circuits. They require more intelligent manipulation than direct acting meters, but are used almost exclusively where high quality records are essential.

Portable Indicating Meters for Central Station Service

H. B. Taylor

PORTABLE METERS often are selected for use in making certain specific tests, and need not be adaptable to other work. In that case the decision as to what type and capacity of meter to use is not difficult to reach. Equipments of this sort usually grow. Unless a general plan providing for this growth is worked out in advance a number of different kinds and different capacities of meters may accumulate, and still there will be occasions when no suitable equipment for a necessary test is available.

Central stations supplying direct current alone or alternating current alone for distribution under conditions that do not demand a variety of tests may employ only one type of portable indicating meter, wound for different kinds of measurements and for different capacities. Generally, on systems supplying different kinds of current, or wherever tests of various kinds and requiring different degrees of accuracy are to be made, there will be an advantage in having meters not only of different ratings but of several entirely different types on hand.

It may be stated without question that any distinct type of meter construction which has stood the test of service well enough to have any commercial standing at this period of electrical development must have some feature in which it excels. This feature may be accuracy under normal conditions, accuracy under abnormal conditions or in certain restricted kinds of measurements, ruggedness, light weight, low cost, legibility or any one of a number of other characteristics. A meter measuring up fairly well to a majority of these requirements, though not necessarily reaching the limit attained by some other meter in any one particular, will have a very wide range of usefulness. Every designer of electrical measuring instruments would like to produce a meter possessing all of the desirable features in the highest degree, but the various requirements in many cases dictate structural details of entirely opposite kinds. The best that can be done is to make a compromise, giving preference to such features as are most important for the service in view.

Commercial types of construction of indicating meters, as often enumerated, are:—the D'Arsonval type, for direct current only; the induction type, for alternating current only; the dynamometer type, for use interchangeably on either alternating current or direct current; and the magnetic vane type, which can be used either on direct current or on alternating current, though usually they are not interchangeable in that respect.

D'Arsonval type meters are those in which the magnetic field acting upon the movable element is maintained by a permanent magnet. Induction type meters operate on the same fundamental principle as induction motors. Dynamometer type meters contain no iron in their magnetic circuits, and operate by mutual attraction or repulsion of fields set up by currents in movable and stationary coils. Magnetic vane types of meter have moving elements consisting of small soft iron armatures pivoted to move under the influence of currents in stationary coils.

The merits and demerits of the several types have been discussed to a considerable extent, so that they

are quite generally understood. No one questions the superiority of the D'Arsonval type for direct-current ammeters and voltmeters, nor the dynamometer type

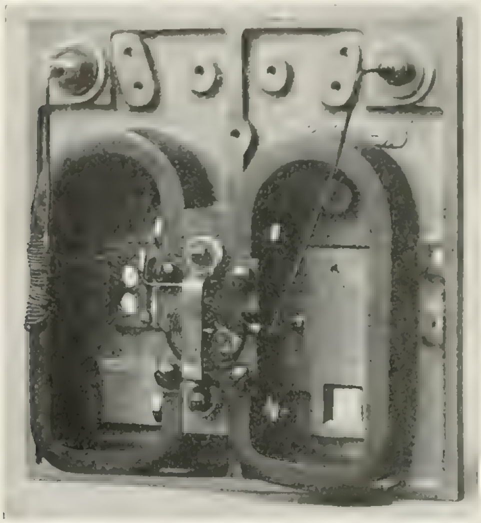


FIG. 1 D'ARSONVAL TYPE MILLIVOLTMETER OF SINGLE AIR-GAP, DOUBLE MAGNET CONSTRUCTION

for alternating current standard and portable voltmeters and wattmeters. In any type and for any service, ruggedness, and hence reliability, is a highly important consideration. The tendency is to accentuate this feature as the art advances. Fragile meters in portable form should be used only on those rare occasions when the nature of the measurement to be made is such that there is no alternative. For the measurements of current, voltage, power and similar work on lighting and power circuits, substantial meters, which are superior in every respect to the delicate apparatus of earlier days, can readily be obtained today.

While it is not advisable to depend too much on a single type of meter, there is much to be gained by standardizing the equipment with a view to making all apparatus for a given kind of service nearly alike when this can be done without sacrificing efficiency. A step in this direction which promotes rather than sacrifices efficiency is to standardize capacities of in-

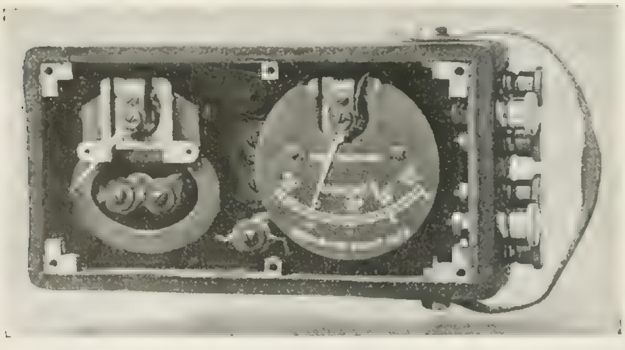


FIG. 2—D'ARSONVAL TYPE AMMETER AND VOLTMETER OF THE DOUBLE AIR-GAP, SINGLE-MAGNET CONSTRUCTION, MOUNTED IN ONE CASE

struments of a given type, making them interchangeable for use with auxiliary devices such as shunts and transformers of various capacities. This plan is applicable to a complete equipment of meters. Direct-voltmeters of the D'Arsonval type are an exception to the rule, as they can readily be made self-contained to cover a very wide range, but even these, when intended for use at pressures above 750 volts, should have external multipliers. Also the work of checking their calibrations can be simplified by having one terminal provided on every portable direct voltmeter for a certain full-scale voltage which should be alike for all. Fifteen volts is a convenient range for this purpose if the equipment includes some low-reading and some high-reading meters.

There is some objection to providing a 15 volt scale on meters for use at higher voltages on account of the danger of burning out the coils through carelessness in making connections. This objection can be overcome by making it a rule in the laboratory to seal the 15 volt terminal after checking calibration, if it is not to be used. Direct-current ammeters with internal shunts, except those having very low current ratings, are less accurate than the ones having separate shunts, on account of the varying temperature

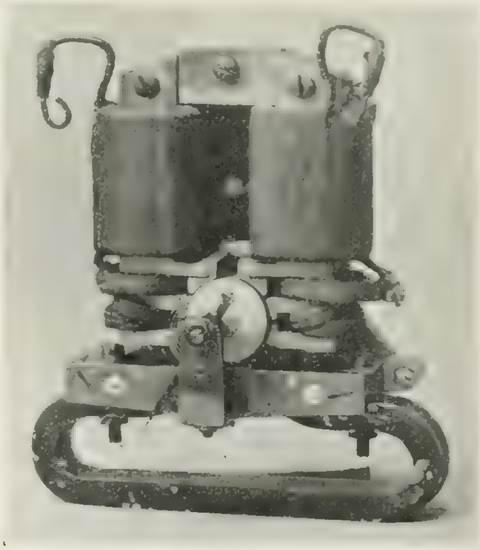


FIG. 3—INDUCTION TYPE AMMETER MOVEMENT

caused by the energy losses in the shunt. They are limited to one or two full scale ranges and cannot readily be recalibrated except by comparison with a standard of corresponding capacity and on a circuit where the load can be adjusted to exact values from full load down. Millivoltmeters, all adjusted to equal scale range and used with separate interchangeable shunts, afford the most flexible arrangement for measuring direct current. If the shunts are compact and substantial the outfit, consisting of millivoltmeter, shunt and flexible leads, is more convenient to use than a self-contained meter because the shunt can be inserted in the most accessible part of the circuit, perhaps on a wall or under a machine. Only the small leads, always with the meter, connect it to the circuit where it would be necessary to provide heavier wire or cable connections for a self-contained ammeter. Four or five shunts can be placed in a small carrying

case. This makes a desirable arrangement for outside work, the one millivoltmeter and five shunts comparing in weight and size with two meters while they compare in scale range with five meters.

Scale marking must be considered when selecting a set of portable shunts. Scales having single sets

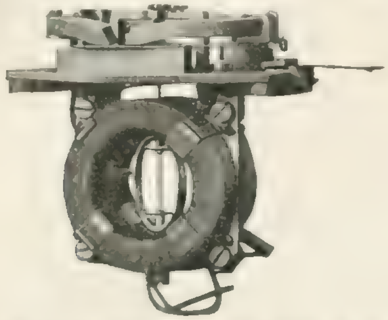


FIG. 4—DYNAMOMETER TYPE ZERO READING WATTMETER

of divisions and single sets of numbers are easiest to read. Single sets of divisions and two or even three sets of numbers opposite the main divisions make a good combination. Double scales, in which there are two sets of scale divisions, are objectionable. A scale marked to read from 0 to 100 can always be read in terms of percent of full load. Where it is on a 100-millivolt meter it also reads millivolts direct and is practically direct-reading in amperes when used with 1, 10, 100 or 1 000 ampere shunts which give 100 millivolts drop at full load. A 100 division scale having 10 main divisions is easily read when numbered 0 to 20 or 0 to 500. Shunts having capacities 10, 20, 50 amperes or multiples of these capacities can be used in connection with a millivoltmeter having such a scale, to give readings in amperes direct. On the other hand, a shunt rated at 300 amperes or a similar rating giving odd values, such as three, six or seven amperes per division, would not permit direct reading of scale.

Before selecting a shunt for use in connection with a given millivoltmeter, it is worth while to consider exactly what each scale division and especially what the fractions of divisions will mean in amperes, and how the main division numbering applies. Where a millivoltmeter will be used with a shunt of a certain capacity most of the time, it is convenient to have the scale marked in amperes. Any capacity necessary for the most complete equipment can be provided for in two standard scale markings, one having 100 divisions and the other 150 divisions total.

Alternating-current meters can be standardized in capacity to still better advantage than direct-current meters, current transformers taking the place of shunts. Either voltage transformers or multipliers can be used in the potential circuits. In alternating-current testing, more meters are used than in direct-current tests. Since several different kinds of meters can operate from one set of transformers the proportion of auxiliary apparatus actually used is small compared with what it seems when considering a single meter. Transformers having several current ranges can be obtained, thus making the transformer and one meter equivalent in scale range to four or more meters wound for different capacities. Multiple-capacity current windings in ammeters and wattmeters help materially in providing good ranges for small work while at the same time keeping them available for operating from the secondaries of transformers. With current transformers all rated at five amperes secondary, and current coils of meters arranged for series-multiple connection, some of the current coils can be rated at 2.5 and 5 amperes and others at 5 and 10 amperes. The 10 ampere connection of coils is useful not only when the meter is directly in circuit, but also in measuring temporary loads beyond the rating of the transformer. Unfortunately the 2.5 ampere connection cannot be used for increasing the legibility of readings when the secondary current is below 2.5 amperes, because this would affect the accuracy of the transformer.

It is not a good plan to complicate a meter by putting unnecessary terminals on it, but all voltmeters and all of the voltage circuits of wattmeters can have one terminal for 110 volts normal, to be used with or without transformer and another for, say, 55 volts or 220 volts normal.

Multipliers, consisting of non-inductive resistors for connecting in series with the voltage windings can be used instead of voltage transformers, but their field of usefulness is limited. For ordinary testing, the transformer is preferable. First, it is safer; also, two or more meters can be supplied from it at the same time without appreciably changing its ratio. It is absolutely interchangeable between meters of different kinds, such as voltmeters, wattmeters and frequency meters. At any voltage above 300, the greater safety in taking readings and handling the meter on the secondary of the transformer as compared with any arrangement bringing line voltage to the meter is sufficient to justify the use of the transformer if it is

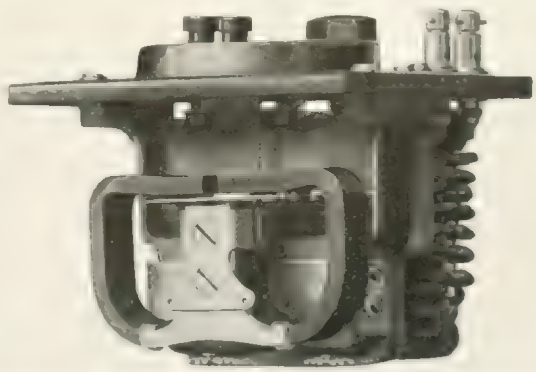


FIG. 5—[illegible] TWIN BALANCE TYPE [illegible] PRECISION WATTMETER

applicable. Of course, the multiplier is the only device that will answer the purpose on direct current. In the laboratory, the multiplier is to be preferred for measurements at odd voltage or frequency on account of its more dependable accuracy. Outside the laboratory, at normal voltage and frequency, there is no

more reliable electrical device than the transformer, because there is nothing that will stand more abuse. Shunts for direct-current ammeters are in the same class in that respect, if properly designed. That is why a meter equipment arranged on the plan outlined herein results in lesser burdens for the metermen on outside work to carry around. They can entrust the shunts and transformers to any kind of reckless help without serious risk of causing errors in calibration.

Mechanical considerations favor the use of low-capacity meters. Heavy conductors and the arrangements necessary for connecting them, internally and externally, are inconsistent with the requirements for highest accuracy. Within the laboratory, the extra time and equipment required in maintaining meters of odd capacities may more than offset any saving in time through the use of direct connected meters. When interchangeable meters are used, any inaccuracy in one of them will be detected sooner than it would if comparison between meters in service were less direct.

Calibration expenses can be reduced to a minimum by reducing the equipment and the time spent in that class of work to a minimum. Secondary standards consisting of five indicating meters with one set of auxiliary apparatus would constitute a complete outfiit. By using one voltmeter as standard for both alternating current and direct current, the numbei could be reduced to four. The five meters mentioned are:—

1 D'Arsonval type millivoltmeter, large size, with high torque and long scale, 100 millivolts range.
1 D'Arsonval type voltmeter, of same design as millivoltmeter, 15 and 150 volt range.
1 Dynamometer type ammeter, 2.5 and 5 amperes range.
1 Dynamometer type voltmeter, 150 volts range.
1 Dynamometer type wattmeter 5 amperes, 150 volts range.

The dynamometer type meters should be designed for high torque and have long scales, especially suited to calibration work.

In addition to the indicating meters, there should be a good Wheatstone bridge available for testing the voltage windings of meters. A potentiometer and a few standard resistances comparable to the ammeter shunts could be used as primary standards. Potentiometers cannot be operated as quickly as indicating meters and they require very steady current. Current for the potentiometer and for the millivoltmeter or 15 volt scale of the voltmeter can be taken from a primary battery or a small storage battery.

A range of 15 volts is suggested because the very low voltage ranges introduce temperature errors due to the relatively large proportion of copper in the windings. Windings for 15 volts or over in direct-current voltmeters have so little copper in them that their changes of resistance within the working range of temperature are negligible. Having calibrated the 15 volt scale, the 150 volt scale can be made to correspond or the percentage correction on it can be determined by measuring the resistance of each winding with the bridge. The same procedure can be followed in calibrating all of the voltmeters and wattmeters. If they are compared with the standard at one voltage they can be calibrated for any other voltage range by means of the bridge.

The dynamometer type of construction is not suitable for portable ammeters on account of the difficulty in making connections to the movable coil which will carry the full load current and at the same time be flexible enough to allow free movement of the coil. Standard meters can be made larger than portables, and can have other features which are not acceptable in meters for general testing. This simplifies the question of connections to movable coils. The dynamometer type standard ammeter, calibrated on direct current by means of a potentiometer and standard resistors can be used on alternating current for calibrating ammeters of other types.

Mercury Arc Rectifiers for Operating Moving Picture Arcs

H. M. Wible

THE BUSINESS of exhibiting motion pictures is now rapidly settling down to a solid and permanent basis. The theatres that are now being erected are better adapted to projection and there is a constant tendency to improve all equipment connected with the business. The day of shadowy, jumpy projection is passing, as better results are demanded by the public and that demand must be reckoned with. Standard equipment to meet with any or all conditions in the field is logically the next step in the development. The present article describes a type of apparatus designed with this idea in view.

THERE ARE approximately 18 000 moving picture theaters in the United States, and probably at least three-fifths of these have only alternating current available. Therefore, as the very foundation stone of the moving picture business is light, it is unfortunate that in moving picture work alternating current does not give as good a light from the arc lamp as direct current. A direct-current arc is also much easier to operate for several reasons. First, the light comes from a concentrated point at the end of the electrode, as shown in Fig. 1, instead of from the arc flame, as in alternating current. This concentrated source is more efficiently utilized by the lens and, as the arc does not waver

and shift in position like a flame, focusing is made much easier and requires less attention. Also, a greater arc length can be used which makes adjustment less delicate, as small changes of arc length cause less effect. There is not the danger that the

FIG. 1—DIAGRAM SHOWING THE POINT SOURCE OF LIGHT IN THE DIRECT-CURRENT ARC

body of the electrode will shut off the light, as often happens with an alternating-current arc because of its short length and flickering flame. The data contained in Figs. 2 and 3 was taken under conditions such as will be found to exist in moving picture theaters; i. e., the lamp was enclosed in a lamp housing; the light was directed through lenses on to a screen at an arbitrary distance of the order of the throw commonly used; and the lens focused to give a clear picture on the screen. The pictures that were obtained were comparable in size to those shown in average moving picture theaters. The photometer readings were taken at the point where the screen had been placed for getting the focus. The values labeled "illumination" indicated by the curves are not candle-power of the arc but are values proportional to the intensity of light at the screen. The constant of proportionality is the same for both curves. These curves cannot be used to obtain absolute values but can be depended on as comparative tests between alternating current and direct current for moving picture work.

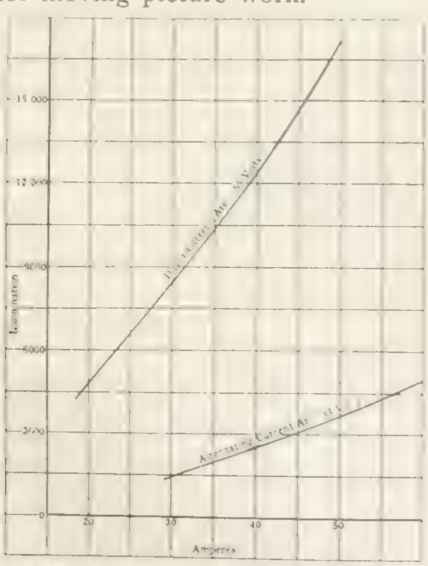


FIG. 2—COMPARATIVE ILLUMINATION OF RECTIFIED AND ALTERNATING-CURRENT ARCS BASED ON THE CURRENT REQUIRED

Since the direct-current arc is so greatly superior to that obtained with alternating current, many operators are making use of mercury arc rectifiers which have been designed for furnishing direct current to moving picture arc lamps, the power being taken from an alternating-current source. The ordinary outfits are manufactured in 30, 40 and 50 ampere sizes ,the design characteristics and general appearance being the same. All direct-current moving picture arcs are of about the same voltage (55), and the operator usually requires all the current the outfits will give, especially when showing colored moving pictures; therefore, it should have the simplest possible method of control.

Each outfit consists of a cast iron main frame on which are mounted an auto-transformer, a reactance coil, a tilting mechanism, a five point dial switch, a bulb and a bulb holder, all enclosed in a perforated sheet steel cover. The auto-transformer

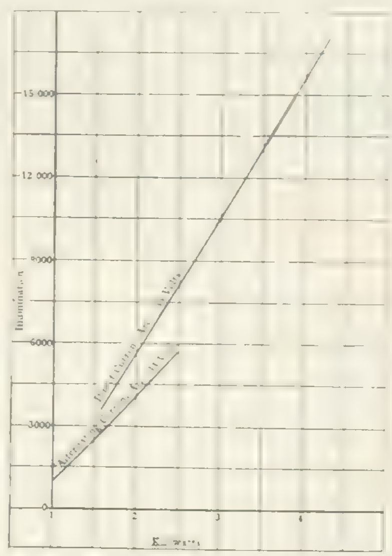
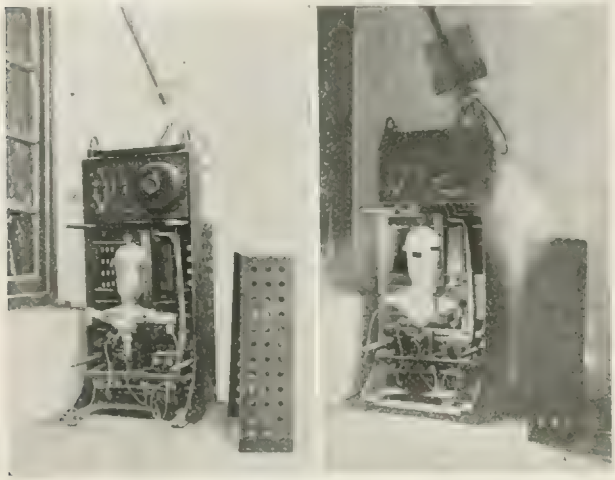


FIG. 3—COMPARISON OF ILLUMINATION FROM RECTIFIED AND ALTERNATING-CURRENT ARCS ON A POWER CONSUMPTION BASIS

with a large reactance coil in the primary circuit serves to give stability to the arc and to limit the short-circuit current (when the arc carbons are brought together in starting), to a value not exceeding 50 percent of the normal rating of the bulb for continuous operation. Four different primary connections are provided to take account of such variations of line voltage from normal as may reasonably be expected. Each outfit is provided with an automatic tilting device, so connected that the closing of the arc carbon circuit causes it to tilt. This feature makes it unnecessary for the operator to leave his position in order to start the outfit and unnecessary to install the outfit in the booth. A tilting outfit capable of continuous operation is not used, as the bulb is not subjected to long periods of tilting. A tilting transformer is not used, as in the case of battery charging outfits, but a tilting magnet is so wound that it in itself performs the function of both transformer and magnet. It may sometimes occur that the bulb is not in operating condition, and as it is important, in moving picture business, that the show be a continuous performance, there is incorporated in these

outfits means whereby connecting links, as indicated in Fig. 4 and Fig. 6, make possible the operation of the outfit as an economy coil to provide an alternating-current arc, and by means of the dial switch (Fig. 4) the current can be varied to the desired value.

There is considerable difference in opinion as to the amount of direct current that should be used



FIGS. 4 AND 5 RECTIFIER OUTFITS WITH COVERS REMOVED
The view on the right shows rectifier in operation.

under various conditions. However, it is the consensus of opinion that within reasonable limits, at least up to 150 feet, added length of the throw has little or nothing to do with additional current. As brilliant a picture can be projected with 30 amperes direct current at 100 feet as at 50, provided the size be the same in each case, the only difference being in the focus of the projecting lenses. There is practically no loss of light in traversing the air for distances ordinarily used for projection. Therefore, 30 amperes direct current is satisfactory for ordinary conditions; 40 amperes direct current will perhaps be required when there is an extra thickness of the film or there is considerable light in the theater, and 50 amperes direct current is generally used for showing colored moving pictures.

Operators claim that means whereby the current of the arc can be quickly varied between films is now an essential feature in the moving picture work, especially in cases of spot light and advertising matter where perhaps 15 or 20 amperes direct current is sufficient. This condition is met by an outfit such as shown in Figs. 4 and 5 whereby the current at the ar is varied by the means of a dial switch controlling taps on the reactance coil. This device permits a quick change in current without loss of efficiency, as the change is made by a reactance coil in the primary circuit.

From the diagram of connections shown in Fig. 6, it will be seen that the alternating current enters at *C*, passes through some portion of the reactance coil, as determined by the dial switch, then to the link connector and into either tap *5* or *6* of the transformer, then leaves the transformer at either tap *2* or *3* and back to the line at *A*.

In the direct-current circuit the current leaves at *7* or *1* of the transformer, flows through one side of the bulb to the lower terminal, then through the relay coil to the + terminal, through the arc lamp to the — terminal and back to *4* of the transformer. The relay serves to open the tilting circuit while the arc is in operation.

In the past there has been one objection to a mercury arc rectifier for moving picture work, namely, that the natural end of life of the bulb may come during a performance of the show and, unless the operator has a spare bulb on hand, the outfit would be entirely out of commission and a complicated condition arise. This objection is now entirely overcome in the design of the new outfit, as it can be operated as an economy coil to provide an alternating current by transferring a link connector from one terminal to another, as shown in the diagram. When the outfit is used as an economy coil the primary circuit is exactly the same as before, but the arc is connected across the center point *4* and to a special tap *5A* of the transformer. This connection cuts the bulb out of the circuit but leaves the side leads of the bulb connected as before, i. e., alive. The alternating-current arc connections are so proportioned as to give a 60 to 70 ampere arc with the dial switch on the high point, which is about the limit in current with moving picture machines now in common use. This gives light somewhat inferior to that with the direct-current connection, but serves in case of emergency to keep the machine going.

Thus the mercury arc rectifier makes possible for projection work the use of a direct-current arc, the ideal for moving picture work, in territory where alternating current only is available, which has the distinct

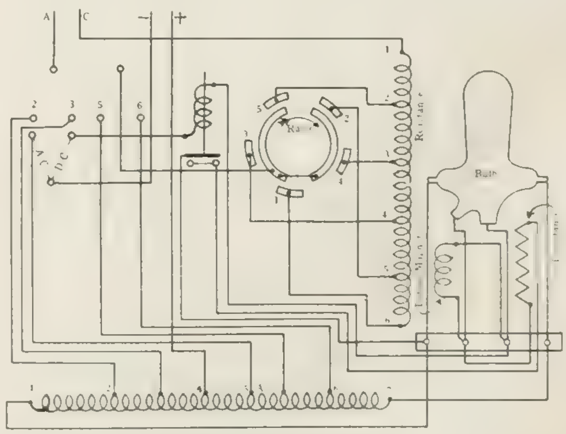


FIG. 6—DIAGRAM OF CONNECTIONS OF COMPLETE RECTIFIER OUTFIT

advantage that it does not produce the flickering light, so trying on the eyes, which is obtained from an alternating-current arc. Also, for the same amount of power input to a rectifier for a direct-current arc and to an economy coil for an alternating-current arc, the direct-current arc gives about 35 to 40 percent greater intensity of light on the screen.

THE ELECTRIC JOURNAL

VOL. XI JULY, 1914 No. 7

Bearings, Lubrication and Alloys

It is the fate of many familiar devices to be taken for granted, and the history of shaft bearings confirms this observation. Few devices so simple in structure and, apparently, so simple in operation, are actually so complex and so difficult to investigate and explain. It is not surprising, therefore, that under such conditions of apparent simplicity and actual complexity, the fundamentals of the theory of bearings were unknown for centuries after bearings were in use and for a hundred years after the advent of steam power gave such a strong impetus to machine construction.

The articles in this issue of the Journal by Mr. Foot on bearing design and lubrication, and by Mr. Johnson on bearing alloys cover an interesting and long-neglected field, and are well worth careful reading by all engineers concerned with the design, operation or maintenance of bearings. While the interesting resume of the history of bearings and of the design of bearings from the standpoint of lubrication given by Mr. Foot is of general interest, the detailed instructions for handling babbitt and for babbitting bearings given by Mr. Johnson should be of particular value to the operating engineer.

The importance of maintaining uniform, correct temperature in molten lead-base bearing alloys was discovered only after numerous troubles were experienced with such alloys in service. These troubles were thought to be due to the inherent properties of the alloy, and this opinion resulted in a strong prejudice against this class of bearing alloys. Experience has shown however that with proper handling in manufacture, particularly with respect to temperature, the lead-base alloys will give excellent service in all ordinary applications. In bearings subjected to very high pressures or to pounding or vibration, the harder tin-base alloys should be used when temperature and other conditions cannot be controlled with certainty, as is the case in most repair work.

The fact of the great difference between the starting friction and the running friction of bearings has become fairly well known because of the general use of gas engines, synchronous motors and other motors having limited starting torque, but the probable reason for this difference, illustrated by Mr. Foot's analogy, will be new to many engineers.

It is a matter of interest that the requirements of electrical machinery for high-speed oil-tight bearings led to the fundamental research work of Tower, Reynolds and Lasche, and to the subsequent application of the theory to machine construction. Without this knowledge of the correct principles of operation of shaft bearings, modern high-speed, large-capacity generators, particularly of the steam-turbine type, would be out of the question.

F. D. NEWBURY

Electricity in Metal Mining

Much has been said and written relative to shop economies in the fabrication of materials into machinery and structures. Fully as important is the matter of conservation and economy in the production of the materials entering into manufacturing operations. Metal mining is a field in which rapid strides are being made by electrical operations, and two important tendencies are well presented in the papers by Mr. W. A. Rankin and Mr. F. C. Stanford in this issue of the JOURNAL.

Mr. Rankin describes the use of steam, formerly used at low economy if not wasted altogether, for recovering metal from tailings heretofore thrown away. This is accomplished through the use of low pressure turbines and electric drive for the regrinding and concentration of both old and new tailings. These results were obtainable only by careful engineering and the use of the most improved types of machinery.

Mr. Stanford describes the installation on a large scale of electric power for all mining operations. Electric drive for secondary operations has long been recognized as economical and dependable but there has been a hesitation about electrification of primary operations, such as hoisting and compressing air for underground drilling. The magnitude of the electrical operations of the Cleveland Cliffs Iron Company makes them pioneers in the field of large complete electrification of metal mines. In this case use is made of cheap power developed from an hydro-electric installation made particularly for this purpose. Similar installations are now under way in other locations, thus showing that the confidence of the mine operators has been won to the use of electric drive for practically all mining operations.

Both of these papers are valuable in their description of advanced methods of operation and suggestions as regards conservation and economy.

W. A. THOMAS

Paul Martyn Lincoln

President-Elect
American Institute of Electrical Engineers

MR. PAUL M. LINCOLN, elected as President of the American Institute of Electrical Engineers for the coming year, is a man who has had a many sided experience. For over twenty years he has been active in various phases of electrical engineering; he has had educational affiliations and has taken an important part in many branches of Institute activity.

Graduating from the Ohio State University in 1892, he entered the employ of the Short Electric Company in Cleveland, and learned at first hand the difficulties encountered in operating electric cars on steep grades with small generators in the power house. He then joined the Westinghouse Electric & Mfg. Company, and was engaged in the testing room and in general engineering work. At the opening of the Niagara Falls Power Company's plant he became its electrical superintendent, and was thus identified in the early and notable days with the first great power plant in this country. He had much to do with the first transmission line to Buffalo, which in the amount of power transmitted and distance traversed was the greatest line of its time. In 1902 he returned to the Westinghouse Company where his operating experience became of great advantage in his work in connection with the general engineering of power stations and transmission lines. For several years he was in charge of the power engineering department, in which position he supervised the design of a large amount of generating and converting apparatus. On the organization of the general engineering department, he was transferred to this department where his large acquaintanceship with operating conditions and operating men has proven of great value. He has thus been identified with the formulation of many of the large projects of recent years and has come into contact with operating conditions, as well as those pertaining to the design and performance of apparatus.

In the American Institute of Electrical Engineers he has presented numerous papers, and was one of the members of the Transmission Committee which began its work a dozen years ago. To the work of this Committee, through meetings and discussions, and through reports and published data, is due, in no small measure, the rapid and successful advance in power transmission. At the time of the appointment of that Committee, not quite twelve years ago, there was no plant in the country operating above 40 000 volts. He has served on many committees, notably by holding the chairmanship of the Committee on Local Organizations for five consecutive years. This has brought him into intimate touch with the conditions and Institute needs in all parts of the country, while his service on the Board of Directors has acquainted him with internal Institute affairs.

As an educator he is professor of electrical engineering in the University of Pittsburgh. In the field of technical journalism he has been for a number of years a member of the publication committee of The Electric Journal.

This experience, covering intimately the development of electrical engineering during the past twenty years or more, supplemented by an unusually wide personal acquaintance, is a peculiarly fitting preparation for leadership in the great national body of electrical engineers.

Mr. Lincoln is a positive, definite, original thinker. Among those who have been most intimately associated with him, as well as those whose acquaintance with him is slight or only through his writings, there is a regard and respect for his opinions and for the straightforward and frank way in which he is ready to express them. He is a man of large vision who will bring to the important office to which he has been chosen high ideals to be achieved by the electrical engineering profession, and a due sense of its obligations to the public which it serves.

The members of the Institute may well determine that the next year will be one in which they should join to do their part in continuing the progress of the Institute under an able leader.

Electrical Installation of the Cleveland Cliffs Iron Company

F. C. STANFORD
Electrical Engineer, Cleveland Cliffs Iron Company

IN PREPARING this paper it is not the intent of the writer [illegible] engineering problems that arise in the electrification of mines, but rather to cover some of the practical details which continually develop during the installation and operation of electrical apparatus in the iron mining industry. The descriptions and tabulations given are all from work done by the Cleveland-Cliffs Iron Company of Ishpeming, Michigan.

THE Cleveland Cliffs Iron Company has electrical equipment which is supplying service to 18 mines. These mines mostly have vertical shafts and range in depth from 400 to 1 500 feet. The principal generating station is an hydro-electric station located near Marquette and consisting of two high-head turbines direct-connected to two 2 800 k.v.a. three-phase, 60 cycle, 2 300 volt, generators running at 720 r.p.m. A reserve plant consists of two steam turbines rated at 1 000 kilowatts each, complete with auxiliary equipment. The high tension distribution is at 30 000 volts carried to four substations over 3 miles of duplicate circuits of No. 2 hard drawn copper wire on steel towers.

Distribution is made for ordinary service up to about two miles from the substations at 2 300 volts with standard pole line construction. These lines vary in size from No. 2 to 300 000 circ. mils, depending upon the load to be carried. For longer distances, up to five or six miles, 6 600 volts is used connecting through 2 300/6 600 volt air-cooled transformers. One motor-generator set is driven by a 600 hp, 6 600 volt, three-phase, synchronous motor. Aside from this the standard practice is to use 2 200 volt motors for all service above 25 hp and 220 volt motors for all smaller sizes. Lighting for mines and buildings is 220 volts and for location houses 110 volts.

All circuits are protected by electrolytic lightning arresters. Multigap arresters were fairly satisfactory at first, but as load was added it was found they would not stand up under the surges induced by the heavy starting conditions.

The principal uses for current are:—hoisting, tramming, air compressors, underground pumps, surface pumps, underground haulage, miscellaneous power, lighting, signal service, etc. The following tabulation shows the amount of current used in a typical month:

Hoisting	219 700 kw-hr.
Tramming	16 900
Air Compressors	497 800
Pumps	398 600
Underground Haulage	109 600
Miscellaneous Power	131 200
Shops	9 100
Lighting	41 100

The total motor load now connected is approximately 16 000 hp, consisting of 4 500 hp in synchronous motors and 11 500 hp in induction motors. As mine service is considered very severe by most central station men a curve of the daily load is shown in Figs. 3 and 4. While this shows a fairly wide variation of load, with some high peaks, there are no serious fluctuations in voltage that will impair lighting service.

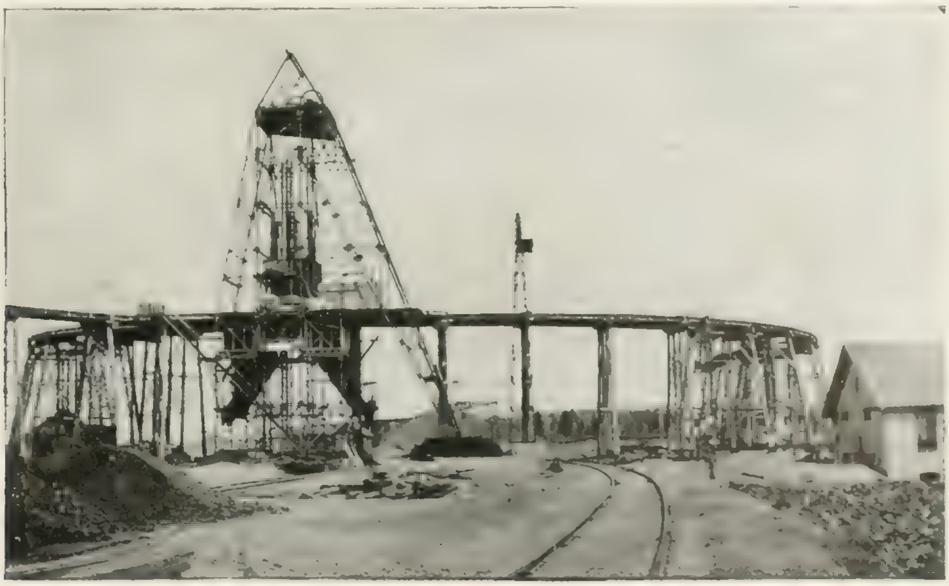


FIG. 1—ONE OF THE HEAD FRAMES AT THE CLEVELAND CLIFFS IRON MINES

All wiring in and about mines must be as nearly perfect as possible, not only that no interruption

of service may occur but also for protection of employees, particularly underground where there may not be as close inspection as in more readily accessible places. Much of the work about mines is also done in unfavorable locations due to moisture, etc.

On all installations of primary motors a standard panel is used with equipment of ammeter, voltmeter, oil circuit breaker with low voltage release and watthour meter. These panels are usually of slate, but for underground service it is the intention to make all future installations on pipe frame mountings only. Marble or slate panels show a tendency to absorb moisture and dirt that makes their use undesirable.

Secondary motors are usually equipped with oil circuit breaker, low voltage and overload relays and watthour meter, wall or pipe frame mounting. The use of fuses is restricted to lighting service only. On wiring for primary motors in power houses and shops varnished cambric, steel taped cable without lead is used. Secondary motors ordinarily are connected by the usual conduit wiring using rubber-covered wire. For conducting primary current into the mines a three conductor cable with varnished cambric insulation rated at 5 000 volts, with lead sheath, jute wrapping and one-quarter inch rectangular armor, is used. A special form of hanger has been developed which securely clamps the steel armor without injury so that when the cable is in the shaft the weight is all supported by the armor. Pump house wiring underground is all done with lead covered steel taped cable. All cables terminate in some approved form of pot head to avoid possibility of puncture, and care is used in grounding armor and lead sheath.

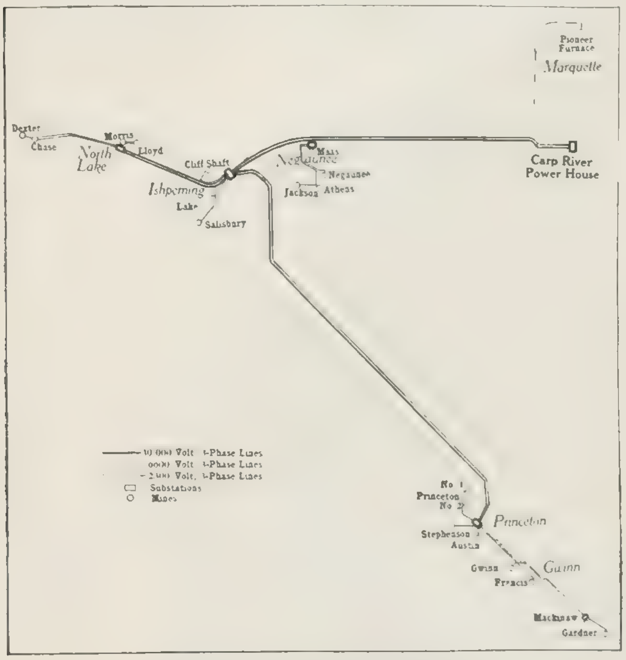


FIG. 2—HIGH TENSION AND DISTRIBUTION LINES OF THE CLEVELAND CLIFFS IRON COMPANY

For the direct-current circuit to operate underground locomotives the feeders are placed in a three inch fibre conduit having a three-quarter inch shell. No trouble has developed and this method is a reliable one, the return wire being bare and carried outside the conduit. The writer, however, is of the opinion that steel armored duplex cable would be

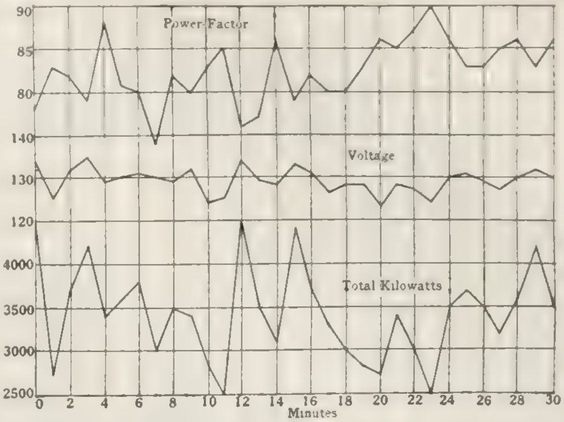


FIG. 3—CURVE SHOWING LOAD CHARACTERISTICS OVER A PERIOD OF 30 MINUTES AT CARP RIVER STATION

cheaper and more satisfactory. This is because the probability of electrolysis would then be reduced to a minimum, as no ground would exist on the feeder excepting at the rail on the levels where service is supplied. And while there might be a slight flow between levels it would naturally be through the iron ore rather than through piping or steel shaft sets. This latter method would cost slightly more for the cable, but would be much cheaper to install.

The question of placing the heavy cables in the deep shafts was quite a problem as space is somewhat restricted and it is necessary to have a number of men to guide the cable past obstructions, and any failure would place them in jeopardy. The best method yet tried is to remove the hoist rope from the cage and then clamp the cable and hoist rope together about every 50 feet and lower the cable into the proper compartment. By doing this work on a holiday usually no delay is caused in the mine operations. It has not been found necessary to use any duplicate cables as up to the present time there has never been a failure in them. Cables are usually tested for insulation resistance on the reel and again after installation, and from time to time re-tests are made. During nearly four years service, no deterioration has been found but rather an improvement in the

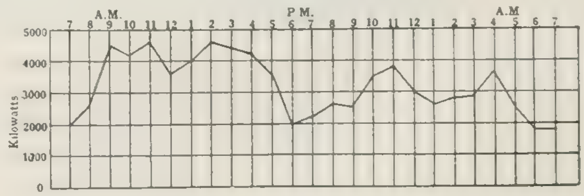


FIG. 4—LOAD CURVE AT THE CARP RIVER PLANT FOR ONE DAY, MARCH 27, 1914

insulation resistance. Re-tests are usually made with a 500 volt "Megger" as it is quick and accurate.

Current for lighting underground in drifts is taken direct from the trolley wire and at shaft land-

ings and pump houses usually a reserve system of lights from the alternating-current circuit is installed. It is the policy of this company to use tungsten lights exclusively, both on surface and underground. For power houses a trial of gas filled lamps is being made, and if reasonable life is shown no doubt these will be used wherever suitable. On all new installations all wiring will be either in armored cable or metal conduit.

HOISTS.

Two types of hoists are in use;—flywheel sets with direct-current hoist motors and induction motors.

At present but one of the first type is in service.

TABLE I—TEST OF FLYWHEEL SET

Depth of shaft Sump to Dump	900 ft. vertical
Net weight of load per trip	9200 lbs.
Weight of skip self dumping	[illegible] lbs.
Size of rope, $1\frac{1}{4}$ inch diameter	2.2 lbs. per ft.
Hoisting	Balanced
Size and shape of drum	Cylindrical 8 ft. x 66 in. wide.
Weight of drum and shaft (from dwg.)	31 650 lbs.
Radius of gyration of drum	3.86 ft.
Total revolutions of drum	35.8

TEST OF 500 HP, 525 VOLT, 60 R.P.M., SHUNT WOUND, HOIST MOTOR

	First Cycle		Second Cycle	
	No 1 Skip	No 2 Skip	No. 1 Skip	No. 2 Skip
Time for hoisting, sec.	66.4	86.85	82.9	78.3
Time of caging, sec.	17.9	20.15	16.9	20 2
Maximum r.p.m.	71	71	70.5	75
Maximum rope speed ft. per min.	1858	1782	1770	1882
Time of accelerating	[illegible]	15.5	20	16
Time of retarding	36	32	38	47
Average r.p.m.	38.1	29.5	27.7	30.7
Average rope speed ft. per min.	965	792	696	772
Maximum motor current	1160	2230	1410	1680
Maximum motor volts	550	520	520	552
Average motor current	495	710	520	683
Average motor voltage	276	212	200	222
Average motor input hp	183.2	201.8	139.5	194.2
Average motor input hp seconds	12 150	17 500	11 560	15 190
Motor copper losses, hp	10.5	21.6	10.8	20.1
Motor copper losses, hp seconds	699	1875	895	1573
Average brake current	450	235	210	180
Average brake voltage	47	62	90	115
Duration of brake	13	7.75	5.5	5.25
Brake hp sec. gen.	368.5	151.2	139.2	145.7
Brake hp copper losses	23.25	16.7	16.55	16.25
Brake hp-sec. copper losses	302.5	129.5	91	85.3
Net hoisting work	10 780	15 344.3	10 434.8	13 386
Average generator current	495	710	520	683
Average generator voltage	276	212	200	222
Output of generator hp sec.	12 150	17 500	11 560	15 190
Average generator I^2R loss, hp	12.4	16.15	12.79	15.62
Average gen. cu. loss, hp-sec.	825.5	1402	1060	1223
Average wdg. fr., and iron loss, hp seconds	628	674	634	647
Total generator losses, hp sec.	1453.5	2076	1694	1870
Speed of set at start of hoisting	690	680	664	685
Speed of set at end of hoisting	[illegible]	600	647	662
Speed of set at end of cycle	680	664	685	690
Output of flywheel hp-sec.	4200	9000	2000	3000
Input to flywheel, hp-sec.	3000	7000	4500	3400
Input to generator, hp-sec.	13 603.5	19 576	13 254	17 060
Input to A.C. motor, hp-sec.	26 800	36 300	32 500	30 000
Input to A.C. motor, not absorbed by flywheel	23 800	29 300	28 000	26 600
A.C. motor losses in hp-sec.	2145	2575	1928	2045
Slip regulator losses, hp-sec.	652	2140	405	501
Shaft hp-sec.	15 200	15 200	15 200	15 200
Overall efficiency	62	44.7	50.2	[illegible]
Kw-hours per ton	1.1	1.6	1.25	[illegible]

This is a Westinghouse set having a 350 horse-power induction motor, a 400 kw., 600 volt, direct-current generator, a 150 kw., 200 volt, direct-current generator, a 25 kw. 200 volt exciter and 25 000 lb. flywheel mounted on one shaft. The generators are connected directly to a 500 hp, 60 r.p.m., first motion hoist motor for ore skips, and a 200 hp, 250 r.p.m. motor with helical gears for the cage or man hoist. The flywheel set has an automatic slip regulator which by changing the resistance in the rotor of the induction motor gives a variation of speed from 650 to 720 r.p.m. dependent upon the load. The armatures of the generators and hoist motors are connected directly by 1 000 000 circ. mil cables without intermediate circuit breakers, the motors having constant excitation in the fields and being controlled through variable fields of the generators. This gives a very reliable service as the flywheel will usually have sufficient stored energy to complete any trip, even if there is an interruption to the current supply.

The ore hoist is designed for a 90 second cycle under 1 000 ft. hoist and gives a maximum hoisting speed at full load of 1 500 ft. per minute. The conditions of operation are indicated by Table I.

There are connected the following induction hoist motors:

Chase Mine	1–200 hp double reduction geared hoist with direct control.
Morris Mine	2–400 hp double reduction geared hoists with remote control.
Lloyd Mine	2–400 hp double reduction geared hoists with remote control.
Cliffs Shaft Mine	1–500 hp double reduction geared double drum, friction, remote control.
Salisbury Mine	1–400 hp single helical geared double drum, friction, remote control.
Princeton Mine	1–200 hp double reduction geared hoist with direct control.
Princeton Mine	1–75 hp double reduction geared hoist with direct control.
Austin Mine	1–150 hp double reduction geared hoist with direct control.
Gwinn Mine	2–400 hp double reduction geared hoists with remote control.
Gardner Mine	1–400 hp single helical geared hoist with remote control.
Mackinaw Mine	1–400 hp single helical geared hoist with remote control.
Athens Mine	1–400 hp single helical geared hoist with remote control.
S. Jackson Mine	1–75 hp double helical geared hoist with direct control.

With the smaller motors we find the direct control, with oil immersed primary reversing drum, is fairly satisfactory, when it is properly designed. The secondary contacts must be of ample capacity and with positive snap into position. The primary reversing contacts should have a positive and quick make-and-break before the secondaries come in. The oil tanks should be so designed that oil will not be thrown out and leads brought out where they may be readily inspected. Ample barriers should be placed between phase leads because with the accurate spotting sometimes necessary with a hoist a quick make-and-break will likely cause surges which may cause a flash over.

For control of large hoist motors solenoid-operated contactors are used exclusively. The only primary switches we have found that are entirely reliable have an air break. While this causes rather an annoying flash and noise, it is a good evidence to the operator that it is working properly.

The line contact points must not make a "butt" contact but should have a wiping contact. This is on account of the possibility of contacts burning together and failing to open when the controller is thrown off. This form of contact is best for secondaries also for

the same reason. This improper condition very nearly caused a serious accident with an old form of contactor which we had in service on account of the motor failing to stop at the surface when the controll was off. The single-phase type of control operation

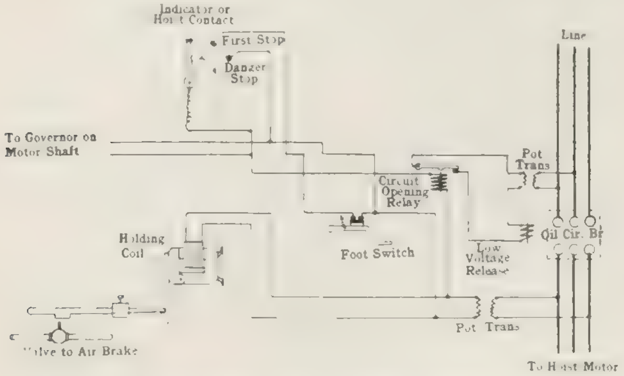


FIG. 5—ELECTRIC HOIST SAFETY OVERWIND

seems to be the simplest rather than to divide the contactor closing coils into three phases.

Hoist motors must have very rugged and substantial frames as, due to the pounding of gears and frequent starts and stops, the service is very severe. Phase leads and coils should be rigidly supported to prevent vibration or distortion under excessive current. Adjustable bearing brackets are desirable. Banding of the rotor should be extra strong on account of the possibility of overspeed. We require that lowering shall be with current on to prevent overspeed.

An electric safety overwind has been developed which has been found very reliable. It is similar to most others which have been brought out, but has been somewhat simplified. The operation is as follows:—

A contact making device is attached to an indicator on the hoist with one contact made about 100 feet below the collar of the shaft. This is controlled by a foot switch operated by the brakeman as shown in Fig. 5, and if the hoist is under control and the switch is opened it does not operate. The final contact closing is positive and is at the danger point. As soon as closed it actuates the circuit opening relay which trips the low-voltage release, opening the motor lines. This permits the holding coil to open and operates the air brake. An over-speed governor may be placed on the end of the motor shaft also which will operate the trip. If the current supply fails for any reason the brake immediately sets.

The curves shown in Fig. 6 covering the hoists at the Morris Mine are characteristic of induction motor service.

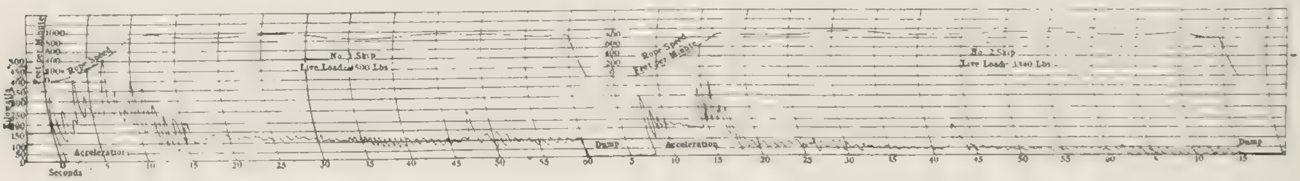


FIG. 6—COMPLETE HOIST CYCLE FOR MORRIS MINE ORE HOIST, TWO SKIPS IN BALANCE

TRAMMING

The word "Tramming," as used herein, refers to the movement of ore on the surface for storage in stock piles. Two methods are in use, principally the "endless rope "system with five ton cars. This requires motors of from 25 to 50 horse-power and is very severe service, particularly in winter when most stocking in done. On account of loading tracks and other governing features, stocking tracks are usually rather crooked, and with many sheaves and rollers the friction load is frequently as high as 75 or 80 percent. When induction motors are used they should have exceptionally high torque and a very liberal allowance of grid resistance. The service likely will be at about the rate of one minute on, with possibly 100 percent overload at the start, and then one minute off while loading the car. The tramming speed may be as high as 1 500 feet per minute, depending upon the tram. Motors for this service must have very heavy and rigid frames, especially if they are to be equipped with solenoid brakes. A typical load curve is shown in Fig. 7.

For short trams under suitable conditions gravity tramming is in use and the motor is only used to return the car. A standard motor answers for this last service.

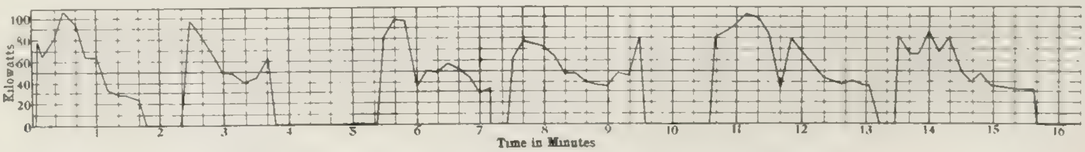


FIG. 7—LOAD CURVE FOR STOCKING TRAM, NEGAUNEE MINE

Three trips out with load and back empty. Heavy reverse curves, 2 400 foot trestle, 2 400 foot pulling and trail-ropes, car weight, 9 000 lbs., weight of ore, 8 000 lbs. Operated by a 50 hp motor.

AIR COMPRESSORS

Iron miners are rather lavish users of compressed air and this company has a number of electrically-driven air compressors. One is a 4 000 cubic feet machine driven by a 625 hp synchronous motor through a rope drive. This is not a variable load compressor, being an adaptation of a steam machine. An "Erie" valve was placed on the suction and as the pressure drops slightly this opens the intake and

the compressor takes the load. This is a rather severe load for a synchronous motor, ranging from friction load to 650 horse-power within a period of two seconds. The motor has given very good service, however, and indicates that modern synchronous motors are reliable for almost any service. It starts readily with the amortisseur winding provided the intake of the compressor is closed.

There are four 2 100 cubic feet compressors, running at 120 r.p.m., each driven by a Westinghouse 325 hp synchronous motor mounted on the shaft and having a belted exciter. These motors show very good efficiences and start readily when the voltage and power-factor of the lines are normal. Tests of overall efficiences of these machines are made from time to time and output computed by Fliegner's formula with orifices of varying diameters to care for various loads. These compressors are two stage tandem.

Another compressor, running at 120 r.p.m., has a variable load device. An interesting curve covering this machine is shown in Fig. 8. Several other small units are belt driven by induction motors. As a reserve to operate air brakes on hoists, small automatic air compressors, driven by three hp induction motors are installed at various mines. These have proven very reliable and satisfactory.

UNDERGROUND HAULAGE.

Underground haulage at all principal mines is with 250 volt, direct-current electric locomotives. These are usually of about 6.5 ton size, with 30 inch gauge. The largest in service is a 10 ton locomotive, but this seems to be somewhat larger than is necessary as the 6.5 ton size will handle all the ore that can be mined. This is quite clear when it is understood that a large part of the time in haulage is devoted to spotting cars and picking up loads, while the actual run to the shaft is but a small proportion of the time. [illegible] rails with No. 00 copper bonds at each joint and past switches. No. 00 grooved trolley is used. In a part of the mines this is placed in an inverted trough, in others it is entirely open. Very few accidents occur. Occasionally a miner will strike the trolley with a drill bar, but he does not repeat the experiment. This company has 28 electric locomotives in service and one armature winder makes all repairs on the 56 motors without trouble and has abundant time for other work.

These underground haulage locomotives are driven by motor-generator sets. Five of these sets are driven by 215 hp, 2 200 volt, Westinghouse synchronous motors at 600 r.p.m. Two sets are driven by induction motors. Very little trouble develops in these and they run continuously. About once in two or three years we find it necessary to true the commutators. This is done while they are in service, with a motor driven grinding machine. Typical load curves from one of these sets are shown in Fig. 9.

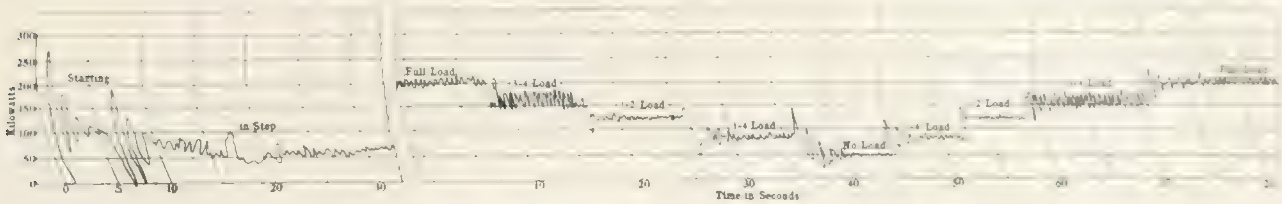


FIG. 8—LOAD CHARACTERISTIC OF A 250 HP SYNCHRONOUS MOTOR

Direct-connected to a two stage duplex 1 700 cu.ft. air compressor. The first portion of the curve indicates the power taken from the line to start and synchronize the motor at no load. The second part shows the operation of the "clearance control" device in its automatic regulation of the compressing load of the motor.

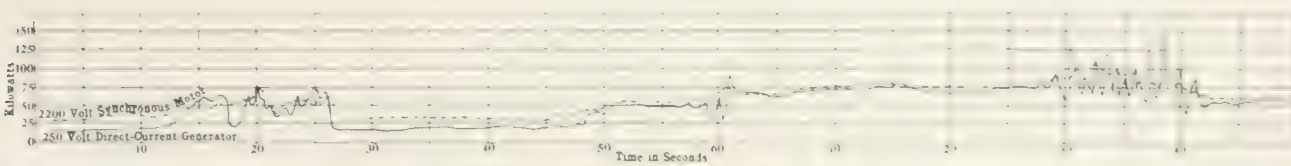


FIG. 9—TYPICAL LOAD CURVES FOR MOTOR-GENERATORS

The load consists of the underground haulage of three 6.5 ton locomotives and 400, 16 c-p lights with an output of 1 000 tons per day and an average haul of 5 700 feet. The grade is two percent in favor of the load.

PUMPING.

The drainage of mines being a matter of great importance the necessity for reliable service in mine pumps is obvious. The centrifugal pump on account of its natural high speed and rotary form lends itself very readily to motor drive. Unfortunately, however, from a mechanical viewpoint it is very lacking in efficiency. About the best that can be expected from a 1 000 gallon per min. pump, designed for 1 000 foot head, is 60 to 65 percent efficiency, depending upon the condition of the impellers, packing, clearance, etc. Having the advantage of low first cost these make a very satisfactory reserve or temporary pumping outfit. This is the application given by the Cleveland Cliffs Iron Company. Each mine has a centrifugal pump installation equivalent

in size to one of the regular units and these are used only for temporary service or in case of emergency. Results of tests made with "V" notch weirs are shown in Table II. A curve showing the character of the load on the motors is given in Fig. 10. The principal mine drainage is by duplex, double acting, pole pumps, although a few triplex pumps of small size are in use. These are driven mostly by induction motors with single reduction gears. These gears formerly gave considerable trouble, but of late all pumps have been equipped with helical cut gears and very little trouble occurs.

TABLE II—OVER-ALL EFFICIENCIES OF MOTOR-DRIVEN MINE PUMPS

	Total Head Ft.	Gal. per min.	Over-all Eff. %
6 stage centrifugal pump	933	987.8	54.1
Duplex double-acting geared pump	833	991.8	84.9
Triplex single-acting geared pump	409	303.8	81.7
4 stage centrifugal pump	409	288	51.3
Duplex double-acting geared pump	509	1406	89.8
5 stage centrifugal pump	498	1153	56.9

It is important that all motors for this service shall have as nearly waterproof insulation as can be supplied, as the conditions underground are usually more or less damp and occasionally water will break through and cover a motor. We have never had a burnout in this class of service and all mines are electrically equipped. Primary motors are used exclusively for this service.

The most interesting pump installation is an equipment of two pole pumps operating at 120 r.p.m., double acting, duplex, throwing over 1 000 gallons per minute under a 1 000 foot head. These are driven by synchronous motors mounted on the crank shaft. They are practically noiseless and give perfect service. The motors come into step promptly and have never given a particle of trouble. These are equipped with motor-driven exciters and each has full switchboard equipment and safety devices. The motors alone weigh 28 000 pounds and are about 12 feet in diameter, with split stator and rotor. These were a little awkward to place in the shaft on account of lack of crane facilities, but it was accomplished without serious difficulty. On account of the high speed of these pumps, small volute pumps, driven by 15 hp. induction motors, were placed in the suction, thus assuring a full supply of water at all times. This is supposed to be the first installation of the kind that has been made in this country.

Other underground pumping applications are small automatic sump pumps operating with the ordinary tank float arrangement. Another use is for sinking purposes. We have three electrically driven sinking pumps, one operating at 2 200 volts and the others at 220. These are about 50 hp each and are very easy to install and reliable in operation. Surface pumping is mostly with small centrifugal pumps and having miscellaneous application, for circulating and cooling water, surface drainage and water supply. These motors range in size from 5 to 40 hp and are all of the squirrel-cage type.

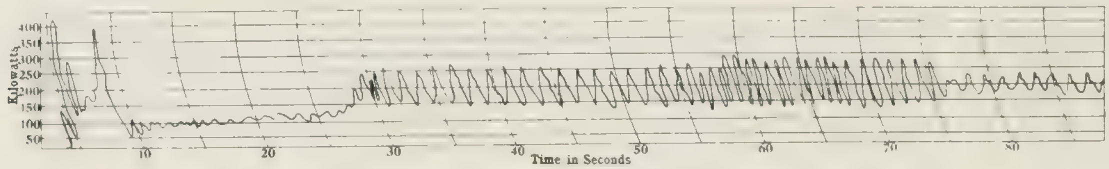


FIG. 10—POWER CURVE FOR A DUPLEX, DOUBLE-ACTING MORRIS MINE PUMP

The pump has four plungers with a 6.5 by 36 inch stroke and is operated by a 350 hp, wound rotor, induction motor at 970 r.p.m. with a gear ratio of 124 to 14 against a head, including friction, of 850 feet. The overall efficiency is 81.6 percent.

CRUSHING

Part of the ore mined is a hard ore and requires crushing before shipment. Crusher house service is very severe for motors on account of the varying load and the large amount of ore dust which gets into the windings. Two 125 hp squirrel-cage motors are used, each driving a No. 8 McCully gyratory crusher, and two 25 hp., each driving a No. 5 McCully crusher. Smaller motors are in service for driving screens, etc. The principal trouble that has occurred was due to cold weather. With no heat in the buildings and temperature ranging down to 30 degrees below zero the oil congealed in the circuit breakers and starting compensators. This was relieved by boxing in the apparatus and placing one or two incandescent lamps within. An occasional burnout occurs in this service, but as it occurs with all makes of motors, and we find the windings full of iron ore, that is presumed to be the trouble. The question of enclosing the motors was considered but, as trouble was so infrequent, it has not been done.

Small crushers are placed in the laboratories. Usually a two or three horse-power squirrel-cage motor drives the entire plant. For evaporating water for ore samples, electric hot plates are in use. These are very satisfactory and all laboratories are now equipped with these in preference to gas.

MISCELLANEOUS MOTORS

The usual miscellaneous applications of power motors are made for machine shop service and to operate sundry auxiliaries. As these are of small size and represent most common service they are not of especial interest.

SIGNAL SYSTEMS

Several different forms of electric mine signals are in use. The most complete is an imported outfit with both visible and audible signals. Heavy waterproof bells are installed at each level and at landings, these being connected in series and repeating at every point. In the engine room for each hoist a pedestal outfit is provided having a paper roll which travels about two inches for each signal. Each time the bell rings a hole is punched in the paper ribbon. By a system of lenses, lamps and mirrors a strong beam of light is projected through these holes and reflected on a ground glass screen. By this method a clear and accurate record of each signal is shown and also a permanent record made on the paper ribbon. Wires for this system are rubber covered and in a lead sheath armored cable. At other mines 110 volt vibrating bells are used, connected in multiple and repeating at each level. For the pushes, waterproof iron boxes have been developed. Some mines are supplied with single stroke bells, current being supplied from small motor-generator sets. All of these methods are quite satisfactory. In addition to the signal equipment, regular mine telephones are supplied at all mines. Wiring for signals and bells is the same as for National Electric Code 600 volt service. There is a demand for reliable waterproof signal switches and junction boxes.

TESTING INSTRUMENTS

A fairly complete set of testing instruments has been provided. This consists of galvanometers, Wheatstone bridge, single and polyphase wattmeters, alternating and direct-current voltmeters and ammeters, shunts, portable potential and current transformers, megger, etc., etc. For locating faults in transmission and distributing lines a slide wire bridge has been developed. This has proven quite accurate and a ground or cross in the transmission line can usually be located within one or two towers, thus saving considerable time and expense.

GENERAL

As mine service in general is rather severe and inasmuch as the safety of employees may at any time be dependent upon the reliable operation of apparatus, manufacturers should recognize the demand for rugged and lasting apparatus. When this requirement is fulfilled, the application of electric drive to mining machinery shows a very marked saving in cost of power and a decided gain in reliability of service.

On the part of operators constant and thorough inspection is essential. Motor clearance must be tested frequently. Oil switches must be carefully cared for and kept in perfect condition. The oil must be frequently changed and tested for moisture. Control apparatus should be gone over daily and contacts kept clean and properly adjusted. Meters should be tested frequently and readings checked to locate quickly any loss in efficiency or defect in operation of apparatus. Mine electricians should be trained to observe all mechanical equipment in connection with motor drive and to know when it is in proper condition, on account of the usual tendency to blame any trouble on the electrical end. If these simple rules are observed electrical drive in mines will be found to be an ideal application.

Babbitt and its Application

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EACH DEGREE of frictional heat that is developed in a machine bearing is a measure of just so much useful power entirely thrown away in that each degree of heat shown in the bearing above that of the atmosphere represents just so much heat removed from beneath the boiler, which, instead of doing useful work only produces so much additional waste in the machine. It is therefore very essential that machine bearings be as nearly perfect as it is possible to make them.

In order that a bearing may run cool careful attention must be given to several important items; the proper materials must be selected for the journal and bearing, the wearing surfaces must be perfectly smooth, of sufficient area and uniform bearing surface. These surfaces must moreover be furnished with properly placed oil grooves which will distribute a lubricant evenly to every portion. A constant supply of lubricant of sufficient quantity and proper quality must also be provided and dust, dirt and all other foreign matter must be rigidly excluded. As a matter of course the mechanical design of the bearing must be right, but the selection of the proper bearing materials and the proper application of those materials are matters of first importance.

A good bearing material must fulfill the following requirements: It must be of sufficient strength to sustain its load; it must not heat rapidly; it must be easily worked; it must have good anti-frictional properties; it must have a long life with small loss of material due to wear; and (with the exception of cast iron on cast iron and hardened steel on hardened steel) it will usually be a material of an entirely different molecular construction from that of the revolving journal which it must support.

Chief among the materials which are used in the construction of bearings are: Cast iron, steel, gun metal, phosphor-bronze and white alloys. Numerous

other materials, many of which are patented, have also been used for bearings with more or less success. Some of these latter are tempered copper, coiled steel wire, aluminum, lignum-vitae and other hard woods, compressed paper, stone and glass compositions.

The white metal alloys are solid materials composed of two or more items such as aluminum, zinc, nickel, tin, lead, copper, antimony, and bismuth in varying quantities and fluxed and alloyed in various ways.

The journal when running may be completely borne by the oil film, but during the time of starting or stopping the film is broken, minute irregularities on the surfaces of the bearing and journal engage, and if the bearing does not yield, as in the case of a steel bearing and a steel journal, small particles are fused and torn out, and these accumulate at the entrance point and may cut both the bearing and the journal.

With a steel journal running in a white metal bearing, the bearing surface is entirely different in its molecular structure, the bearing inequalities are not strong enough to resist the minute inequalities in the journal, and so instead of fusing they yield and are smoothed out. Consequently the bearing surface, instead of being injured by contact and momentary high co-efficient of friction, is smoothed and burnished, thus preparing the way for a uniform wedge oil film, with a minimum co-efficient of running friction.

White metal alloys have other advantages to recommend them for bearings besides their antifrictional properties. They are very easily worked and can be melted in an ordinary iron ladle so that no special equipment is required for the replacement of worn bearings, they are very long wearing and show but little loss of material due to wear even after long service; they tend to reduce shock on machines as well as to deaden noise; and they can be very readily provided with grooves for lubrication and are very easily fitted to a uniform bearing.

A fault to which all white metal alloys are heir is their liability to melt and run from the bearing shell, should accidental overheating take place. It is to be remembered, however, that although other materials do not melt and flow when overheated, an equal amount of heating will cause equally disastrous results to their properties as bearing materials.

All of the white metal alloys which are used in the construction of bearings are somewhat erroneously called babbitt metal. In 1839 a patent was granted to Isaac Babbitt for a special type of bearing enclosing a soft metal alloy. The features of this bearing were lips extending around the ends of the soft metal to retain it in case of accidental heating and to prevent the soft metal lining from being crushed or spread out under severe pressure. The alloy which Babbitt used in his bearing was probably composed of tin 24 pounds, antimony 8 pounds, and copper 4 pounds, to each pound of which was subsequently added two pounds more tin. This gives a metal composed of 88.88 percent tin, 7.4 percent antimony, and 3.7 percent copper. Metals of this type which approximate 90 percent of tin in their composition, are now called U. S. Government Standard or A-1 babbitt, and all other white metal alloys on the market for use in bearings, no matter what their composition, are called babbitt.

Genuine babbitt, when properly made, has a low melting point, is easily worked, has good antifrictional qualities, and will stand a large amount of careless handling, but the constantly increasing cost of tin has made it necessary to secure a good babbitt with a cheaper metal as a base. Laboratory tests show that a lead base babbit will give very good results, but such tests of bearing materials are difficult and uncertain and apt to be misleading. Similarly, chemical tests cannot be wholly relied upon, since a very great deal is dependent on the actual making of the babbitt. But laboratory and chemical tests taken in conjunction with actual service tests furnish very reliable data and a bearing metal developed along these lines may be counted upon to give consistent results in practical work.

Babbitts made up according to nearly 300 different formulae are at present on the market. It would be of very great benefit to the users of babbitt if this number were greatly reduced and the process of manufacture so standardized as to insure a uniform quality of alloy. Except for a few cases, but two babbitts, one a lead base alloy, the other a tin base alloy, each being the best that can be made, are required for a complete line of bearings, ranging in weight from a few ounces to several tons. The best quality of high grade metal should invariably be used.

MELTING THE BABBITT

Babbitt used for bearings is melted in large iron pots or kettles and the molten metal kept at a constant temperature of about 465 degrees C. A constant temperature is of very great importance and is most satisfactorily obtained by using a gas flame controlled by an accurate electric temperature regulator, such as is shown in Fig. 1. The regulator is set to give a temperature variation of five degrees above and below the desired point, the gas being turned low when a temperature of 470 degrees C. is reached and again turned on when the temperature falls to 460 degrees C.

The temperature should be brought up slowly and the babbitt thoroughly stirred, especially when new babbitt is being melted or when old babbitt, which has been allowed to solidify in the pot, is being remelted. This is necessary in order to prevent certain of the constituent metals from rising to the top and becoming oxidized, as well as to prevent the heavier metals from sinking to the bottom of the pot, thus producing a non-uniform alloy. There is very little probability of these difficulties being encountered after the

proper working temperature has once been reached and as long as such temperature is maintained; but stirring at frequent intervals all through the process of working the babbitt is beneficial. In order to reduce oxidation, the surface of the molten babbitt should be kept thoroughly covered with powdered charcoal or with graphite. Scraps of lead, solder or other metals

FIG. 1—A [illegible] CASTING MACHINE

Used in the manufacture of small white metal bearings. The metal pot is shown together with its automatic electric temperature regulator.

or alloys should never be thrown into the babbitt pots and any dross that may form on the surface should be removed at least once a day.

BEARING SHELLS

Bearings are seldom made of solid babbitt, except in the case of small die-cast bearings, and in a few rare cases in railway work. Bearings made in die-casting machines are cast complete with oil grooves and oil ring slots and need but be reamed, faced and turned before being ready for insertion in the bearing housings. A die-casting machine is shown in Fig. 1 and a group of finished solid babbitt bearings made in this way is shown in Fig. 2. As a general rule, babbitt is used only as a lining in bearing shells of cast iron, malleable iron or bronze.

Cast iron is the most commonly used material for the bearing shells of all types of stationary machines, on account of its strength, good working qualities and low cost. Where it is necessary to provide greater strength and toughness at moderate cost, malleable iron is used. Cast steel is not a good material, owing to its tendency to warp when the casting strains are relieved and also after babbitting. Bronze is used for bearing shells in railway work because its use makes certain the completion of a run, even though accidental heating results in melting the babbitt lining and causing it to run from the shell.

All cast and malleable iron bearing shells are provided with cast anchor holes to hold the babbitt lining in place and prevent its turning with the revolving journal. These anchor holes are made by attaching to the green sand cores of the bearing shell mold, baked sand anchor cores of such size that the anchor holes will be of the correct dimensions after the casting is machined. Bronze shells properly tinned require, as a usual thing, no other provision for holding the babbitt lining in place; but, in some cases either anchor holes are drilled diagonally or under-cut grooves are added to make doubly sure that the babbitt lining does not become loose. If anchor holes or grooves are used with bronze shells, they should be few in number and as small as possible.

Iron bearing shells should be cleaned before babbitting and all sand and scale removed by tumbling, sand blasting or pickling in a hot soda ash solution or in muriatic acid. If necessary the sand should be loosened from the anchor holes by hand, for it is absolutely essential that no sand or grit remain to work its way into the babbitt lining. To assure uniformity in grain, wear and thickness of lining, all bearing shells should be bored before babbitting.

Bronze bearing shells should be tinned by immersion in half and half solder before babbitting, great care being taken to secure a perfectly uniform clear film of tin over the entire surface to which the babbitt is to adhere; otherwise loose linings will result. The parts of the shell not to be tinned should be coated with a thin mixture of talcum water. Tinning on iron cannot be depended upon since, at the temperature of molten solder, iron and solder do not alloy. Hence the coating will strip or peel when cold, while if the temperature is raised to that at which iron and solder do alloy, the solder will be oxidized and will not adhere to the iron.

All iron shells must be preheated to a temperature of from 100 to 150 degrees C. before pouring the babbitt. The higher temperature is as a rule the better to use, except where a lining is being poured in a very heavy shell, when it may be necessary to use the lower temperature to prevent the babbitt from cooling too slowly. Preheating should be done in an oven, but may be done over a gas or coke fire, in which case the surface to which the babbitt is to be applied should be turned upward, as otherwise a greasy deposit will be formed, which will prevent the babbitt from adhering properly to the surface of the shell and will cause loose linings. Bronze shells are usually poured as soon

FIG. 2—A [illegible] OF [illegible] BEARINGS OF THE [illegible] BABBITT TYPE

as they come from the tinning pot and while still hot from the tinning operation. The mandrels should be preheated to a temperature of from 100 to 150 degrees when pouring babbitt into the shells, but for bronze shells a somewhat lower temperature should be used. After the first few bearings are poured, it will become necessary to plunge the mandrels into water each time

to reduce their temperature to the proper value. Oil holes in the bearing shells are filled with asbestos or wood driven against the mandrel and the joints are made tight with clay.

POURING THE BABBITT

Very careful attention should be given to the way in which the molten babbitt is poured into the bearing

FIG. 3—SELF-SKIMMING LADLES
Showing inside bridges for predetermining the size of the metal stream in pouring. Leather holders for these ladles are shown at the right.

shell, since this is perhaps the most important operation of all. To secure good results, the babbitt must be poured at the correct temperature. If the babbitt is poured at too high a temperature, extreme shrinkage will occur, resulting in porous areas in the lining and in broken anchors; furthermore, the babbitt will be oxidized, softened and dirty and its antifrictional qualities will be lowered. If the babbitt is poured at too low a temperature, a lining having a coarse granular formation is the result. If the shells and mandrels are too cold, blowholes and similar defects will form, and the lining will shrink away from the shell in cooling. If the temperature of the shell or mandrel is too high, the babbitt will cool too slowly and the heavier metals will have time to settle, producing a bearing which will be soft at one place and brittle at another.

A ladle of the self-skimming type should be used, preferably one having a welded or riveted sheet iron

FIG. 4—AN EXPERT POURING BABBITT
Showing the correct method of holding and steadying the ladle during the operation.

bridge, as shown in Fig. 3, to give the right size of stream for the bearing being poured, thus preventing splashing, as well as keeping dross from being poured in with the babbitt. An expert pourer of babbitt, with the use of an asbestos pad or a hand leather, grasps the handle of the ladle close to the bowl and standing almost perfectly rigid with his arms braced against his body, as shown in Fig. 4, pours in a steady even stream without any splashing or surging of the metal in the ladle.

The best results are obtained by pouring the babbitt with the bearing shells in a vertical position. If it is impossible to place the bearing in a vertical position due to the irregular shape of the mandrel, it may be inclined and poured at the most convenient point. When split bearings are poured at an angle, care should be taken to place the shell so that the face is nearest the table. Split bearing shells are sometimes placed horizontally with the convex side up over the mandrel on a surface plate, and the babbitt poured through holes left in the casting for the purpose. For very large bearings, the shells are more conveniently placed concave side up and the ladle moved along the edge of the shell as the babbitt is poured.

Babbitt, especially the lead base alloy, is weak while hot and bearings must not be roughly handled or thrown about while the lining is cooling. If the

FIG. 5—MANDRELS FOR BABBITTING SPLIT BEARINGS
Showing provision for oil rings and grooves and the completed bearing.

bearings receive rough treatment before the babbitt is cool, anchors are liable to be broken off and the lining loosened.

FINISHING

The finishing of bearings is a well known problem of ordinary machining and fitting which has been fully described and discussed elsewhere and which need not be gone into in detail here. Metal fins and burs are readily removed with an ordinary draw knife or spoke shave or with a hot soldering iron. Lubrication holes are cleaned out with a hot iron, and all large bearings are thoroughly peened before machining. Oil holes are generally cut in the surface of the finished bearing by hand (except in die cast bearings) because in most cases the babbitt lining is too thin to allow casting the grooves.

REPAIR WORK

The easy working qualities of babbitt make it especially suitable for repair jobs in the field. A good tin base alloy, on account of its ability to stand more mistreatment than a lead base alloy, should generally be used for this work. When no equipment is at hand and the cost of building a mandrel is prohibitive or the time required to build it cannot be spared, successful work can be done with a mandrel of sheet

iron. Paper may be used for bore allowances, asbestos cord to provide cast oil grooves, and clay and friction tape to seal up openings. It is even permissible in some cases to pour the babbitt into the properly prepared bearing shells with the journal in place, but the housing cover should be heated and clamped in position to heat up the housing and axle. All bearings should be poured at once and great care taken, especially with small journals, to prevent springing.

The babbitt may be melted in the pouring ladle over an open fire and the temperature assumed as right when a pine stick used for stirring, chars but does not ignite. The mandrel temperature is right when water evaporates rapidly from its surface without sputtering.

SUMMARY

The points to which attention must be given to babbitt bearings successfully are: Choose a good, properly blended alloy made from pure metals; melt it slowly, thoroughly, and without overheating and keep it at a constant temperature while working; have the surfaces of the shell dry and clean; warm them to the proper temperature, and if of bronze, tin them as well; have the mandrel correctly leveled, lined and centered, and likewise at the proper temperature; stir the metal thoroughly before pouring and dip it from the bottom of the pot, pouring evenly and steadily without surging, splashing or pocketing air; machine, peen, scrape, and fit the bearing accurately to the journal; and have oil holes open, oil grooves clear, and surfaces free from sand, dirt or babbitt chips.

Elements of Bearing Design and Lubrication

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STRANGE as it may seem, the action of oil in a bearing was unknown until about 1885, when Beauchamp Tower, at the request of the Research Committee of the British Institute of Mechanical Engineers, made his famous experiments. Since Tower's experiments others have followed with much valuable and interesting data, the most famous being Prof. O. Reynolds, who made a mathematical analysis of this subject.* From these later experiments, if we exclude all other fluids and confine ourselves to the action of oil as a lubricant, in cylindrical bearings of a certain definite type, and extend its use only to the limits usually employed in stationary apparatus, certain simple relations can be brought out that materially assist the engineer in designing highly efficient bearings and enable him to make applications of these principles to meet his needs.

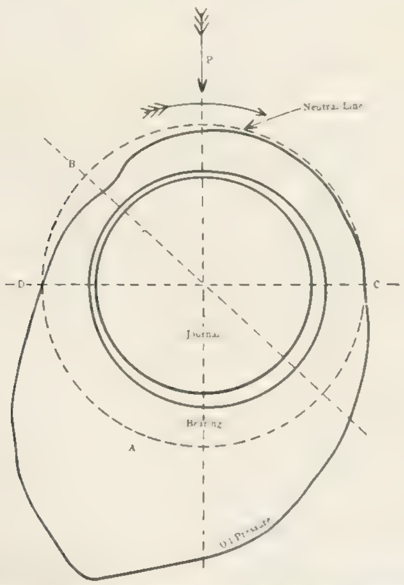


FIG. 1—DIAGRAM SHOWING DISTRIBUTION OF OIL PRESSURE ABOUT THE CIRCUMFERENCE OF AN OIL SUPPORTED JOURNAL

Tower found by means of drilled holes and pressure gauges that, with a journal running in a sleeve bearing, the journal was entirely oil borne and gave a record of pressure like that shown in Fig. 1; that the shaft takes an eccentric position in the sleeve as shown, the pressure reaching a maximum at *A* and becoming negative at *B;* and that in the direction parallel with the shaft, the pressure is maximum at the center and minimum at the ends of the bearing.

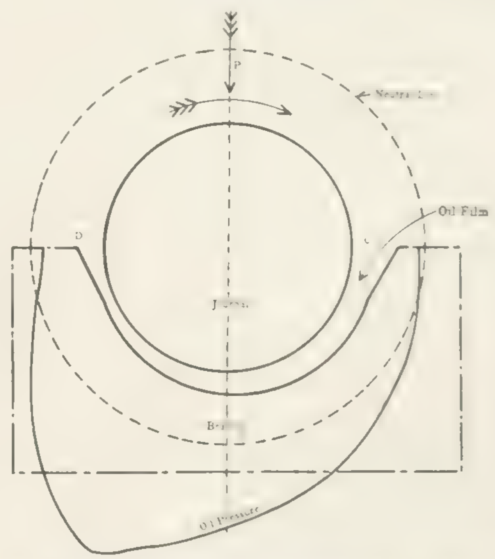


FIG. 2—OIL PRESSURE DISTRIBUTION CURVE FOR A SPLIT BEARING

Let us call the side *C* of the wedge shaped supporting film the entrance and the side *D* the exit, and apply these same conditions to a split bearing Fig. 2 with the entrance at *C* and the exit at *D*. To start the journal from rest with a bearing as shown in Fig. 2, the coefficient of friction will be about 0.4; with a

*Philosophical Transactions, Vol. 177.

small amount of motion the co-efficient drops quickly to 0.05 and less. This continues until at a velocity of about 60 or 70 feet per minute, it drops again to about 0.005 or less and may go as low as 0.001, depending upon conditions; that is, it may be only 1/400 of that required for starting.

With the understanding that no attempt is being made to explain the laws of fluid friction, an analogue may be used to illustrate the three conditions of friction, which for convenience will be named as follows:

1—*Static* friction is represented by a condition of rest, without oil between the bearing surfaces. The torque required is that which is just sufficient to start motion from rest.
2—*Solid* friction occurs during a time of low velocity; it is represented by continuous motion on a solid supporting film.
3—*The Perfect Film* occurs at a higher velocity and is represented by continuous motion on a different kind of supporting film.

A few sheets of stiff paper and a block of rubber can be used to illustrate this as shown in Fig. 3. At slow speed the sheets will slide on one another, but at increased speeds the sheets will roll over. For experiment they can be bent to the shape shown. The speed at which the film changes between solid and perfect firm cannot be determined accurately, but with bearing pressures used in electrical apparatus this change may occur between 60 and 120 feet per minute

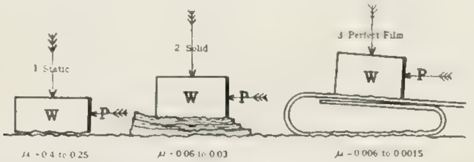


FIG. 3—AN ANALOGY OF THE PHENOMENON OF FLUID FRICTION IN THE SHAPE OF A BLOCK OF RUBBER AND SHEETS OF PAPER

journal speed. Electrical apparatus with few exceptions operates at journal speeds between 800 and 2 000 feet per minute. Therefore, in this article, only the third condition, perfect film, will be considered.

By referring to Fig. 4, which shows the results of Lasche's experiments* (we may here remark that the coefficient is rather high and would have been lower with a lower point of entrance), and keeping within the limits of speed and pressure usually employed, a few simple relations are obtained that are reasonable enough to permit their application to conditions ordinarily met with in practice.

1—At the same speed, the pressure multiplied by the co-efficient of friction equals a constant.
2—For the same pressure the coefficient of friction is approximately constant for the range of speeds used.
3—Within the usual working limits the loss will be in direct proportion to the speed.

Let T = Foot-pounds torque of bearing friction.
W = Load in pounds.
μ = The coefficient of friction.
D = The diameter of the journal in inches.
N = Revolutions per minute.

Then $T = \frac{D\mu W}{24}$ and

Horse-power loss $= \frac{TN}{5250} = D \times N \times \text{constant} = \text{velocity} \times \text{constant}$.

From this it will be seen that the loss is approximately in proportion to the speed.

*O. Lasche, Berlin. "Bearings for high speed." English translation. Pub. Trac. and Transmission. London, 1903.

An application of these principles can be shown in connection with Fig. 5, which shows a shaft with two rotating elements, making 500 revolutions per minute, the total load being 35 400 pounds.

The reaction at *A* to the bearing shoulder with a 10 by 25 inch bearing gives a stress on the outer fiber

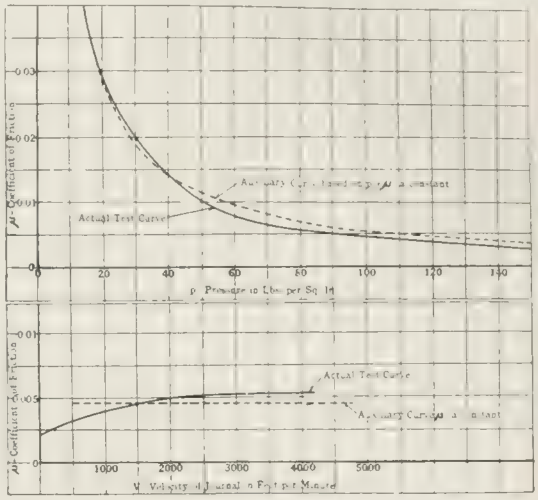


FIG. 4—CURVES SHOWING THE EFFECTS OF VARIATIONS IN PRESSURE AND VELOCITY ON THE COEFFICIENT OF FRICTION

In the upper curve the velocity was maintained constant at 1 970 ft. per min., and in the lower, the pressure was maintained constant at 92.25 lbs. per sq. in. In each case the temperature of the bearing was 50 degrees C., the bearing being flooded with 1.4 pints of oil per minute.

at the neck of the journal of 2 575 pounds, calculated as follows:

Reaction × ½ bearing length = fibre stress × section modulus.*

$$\text{Fiber stress} = \frac{\text{reaction} \times \frac{1}{2} \text{ bearing length}}{\text{Section modulus}} = \frac{20\,200 \times 12.5}{0.098 \times 10^3} = 2\,575 \text{ pounds.}$$

At the neck each outer fiber has an alternate compressive and tensile stress applied, equal to 2 575 lbs. per sq. in., and this cycle is repeated 500 times per minute. From this point of view it looks as if the first thing to decide in the choice of a bearing is the selection of a working neck stress rather than the oil pressure per square inch. This stress passes through a complete cycle every revolution; therefore it should be

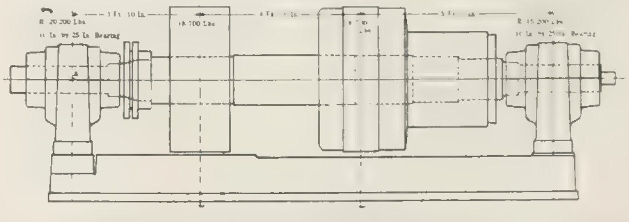


FIG. 5—WEIGHT DISTRIBUTION ON THE BEARINGS OF A 1 000 KW, 500 R.P.M. TWO-BEARING MOTOR-GENERATOR SET

low for high speeds and may be higher for lower speeds. There may be other stresses to take into consideration such as tension, bending due to belts, crank action, etc.; and also the bearing loss is about in direct proportion to the bearing diameter for the same speed. Therefore, in the choice of a bearing there is an oppor-

*The section modulus for a round section is $\frac{\pi d^3}{32.2}$

tunity for good judgment which should be based on actual data and experience.

DESIGN OF BEARINGS.

When torque is applied to a shaft and the journal begins to move, the bearing should be so supported that it will adjust itself to the journal and equalize the load over the entire bearing, and thus give an oil film of uniform thickness in a line parallel with the shaft. Small bearings, or self-contained outfits built with special tools and fixtures may not require this self aligning feature, the limits used being accurate enough to give uniform alignment. But larger outfits, built from a number of assembled parts should embody this self-aligning principle.

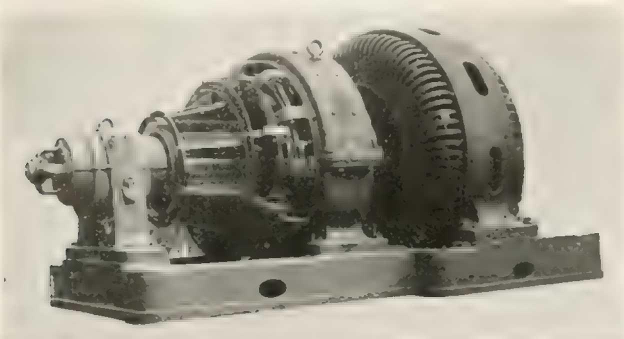


FIG. 6—ASSEMBLED VIEW OF MOTOR-GENERATOR SET SHOWN IN FIG. 5

Years ago engine builders adopted a ball and socket seat for this purpose. Some manufacturers prefer that design today, and for certain classes of apparatus there may be need for some such arrangement. But for the small limits of deflection and the higher speeds used in electrical apparatus today, a simpler arrangement is used, as shown in Fig. 7. An annular ring is turned in the center of the bearing shell for about one-fifth of its length, and this rests upon a corresponding support in the housing; the bearing ring extends down over the sides of the support to take up the thrust due to end play. This is a very effective and simple arrangement and is the type of support referred to when self aligning bearings are specified. The other type is used for some designs, when larger limits of self alignment are necessary and is known as a spherical-seat self-aligning bearing.

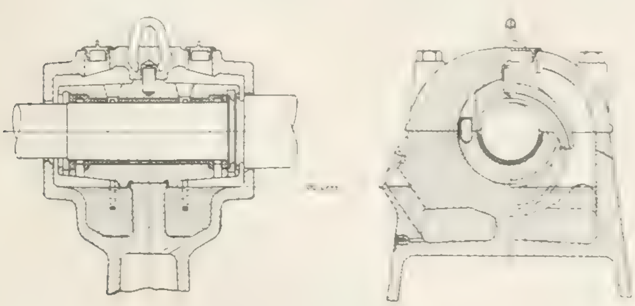


FIG. 7—SECTIONS SHOWING PRINCIPLES OF CONSTRUCTION IN A MODERN TYPE OF BEARING

[illegible]

Up to a few years ago many of the methods of applying the lubricant were wrong, both in manner and point of application. Oil grooves were frequently cut in the zone of maximum pressure. This was evidently wrong, and when the bearing heated more grooves were cut, which too frequently made matters worse. Many different schemes were used to feed the oil and nearly all were based on the minimum limit of oil rather than the maximum supply. There was good logic in this for nearly all lubricants, once used, were then a total loss, whereas now, owing to improved oil protection, the oil used is used over continuously without loss. The different oil feed devices consisted of drop feeds, capillary wire, wicks, wipers, vibrating needle feeds and compression grease cups. The patent office record from the middle of the last century contains a wonderful history of lubricating devices. Sometimes there is need on special applications for one or the other of these devices but to tickle a 20-inch bearing with a vibrating needle feed would look strange today.

About 1860 a ring lubricated bearing was used by Benjamin Hick & Son, Bolton, England. This is shown in Fig. 8. The idea was a good one but its application was unfortunately wrong. The lower bearing was cut through the center, in other words, they put the oil groove in the lower bearing. Instead of the oil passing from the ring to the shaft, then to the entrance trough at the side of the bearing, the oil passed entirely over the shaft, the only oil that got into the bearing being that taken laterally, due to suction at the negative point. However, this was some improvement over previous devices since it paved the way to the employment of a larger oil cellar and a more liberal supply of oil. Since then many have tried to replace the oil ring by different types of chain looped around the shaft, spirals of spring wire and other methods, but for all around dependable duty the oil ring has demonstrated its ability to do the work and has now become a standard for all stationary electrical apparatus and also for most of the machinery of commerce.

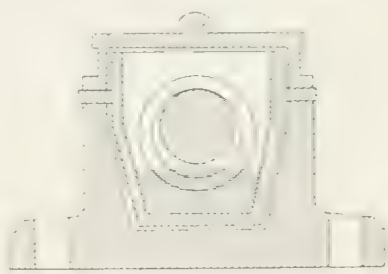


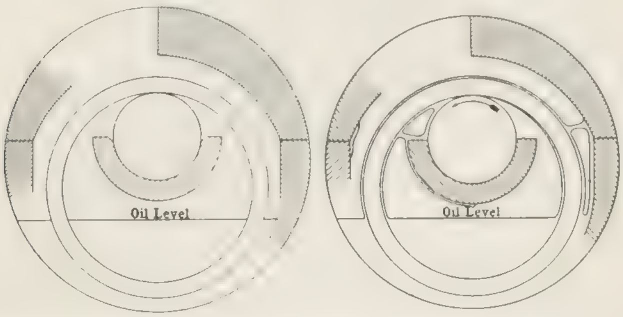
FIG. 8—ORIGINAL RING-LUBRICATED BEARING AS USED IN 1860

When bearings are fed by gravity or oil pump systems, the oil feed pipes pass through the side of the bearing into the entrance trough and the overflow or return pipe is set to maintain a fixed operating oil level. The oil rings should be used and an operating oil level maintained at all times regardless of

the type of oil feed. This rule is imperative. Many reported bearing troubles are due to the neglect of this feature.

OIL PROTECTION

Before the advent of electrical machinery, little attention was paid to oil protection and the recovery of used oil was rather rare. A gang of wipers went over the machinery and wiped up the oil. The familiar oil troughs and grooves for collecting and draining the oil were then quite a common feature in



FIGS. 9 AND 10—DIAGRAMS SHOWING THE APPEARANCE OF THE OIL WHEN STATIONARY AND IN ACTION RESPECTIVELY

machine design. It was common practice to speak of a bearing taking so many pints, quarts or gallons of oil per day in the same manner that the locomotive engineer now speaks of the oil used per trip.

When engine-driven electric units came into use, most of the insulation break downs were due to inefficient oil protection on the engine bearings. Some engine builders today do not give the matter sufficient attention. The fact that a bearing is poorly protected against escaping oil may not be so apparent at slow speeds until the daily accumulation is noticed, but with the high speeds now used on electrical apparatus, if this were not properly guarded against, the amount of oil thrown out even in a few minutes would be quite a serious matter. The development of efficient systems of oil protection was due mainly to electrical

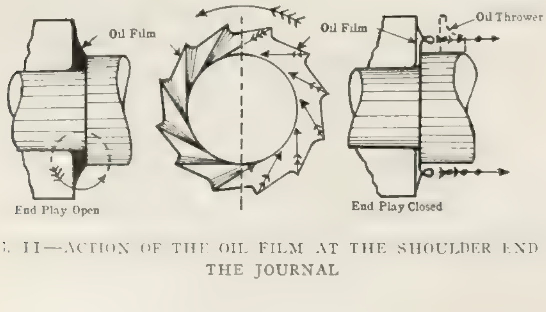


FIG. 11—ACTION OF THE OIL FILM AT THE SHOULDER END OF THE JOURNAL

engineering firms with whom better oil protection was a matter of prime necessity. A careful study was made of the action of the oil at both sides and ends of the bearing, a few of the results of which are herein described.

When standing, the condition in a bearing housing will be similar to that shown in Fig 9, with the oil ring on the shaft and extending down below the oil level. Assume that the side walls are close to the ring as shown in Fig. 9. As the journal speed increases on the ascending side of the oil ring the oil divides into two streams, as shown in Fig. 10, one upward with the ring, the other over the oil surface toward the side wall. If the speed is high enough the oil runs up the side wall into the cap and from there sends a solid stream of oil to the oil ring; the space between the ring and ascending oil stream is filled with a rotating oil film. At the descending side of the oil ring similar conditions will be noted, but reversed, the stream passing from the bearing to the oil ring and the film bounded by the stream, the oil ring and the journal. When the oil ring wobbles, the stream misses the ring and falls on the cap. This action on both sides of the revolving oil ring will keep the bearing split supplied with oil which will be pumped around the split to the shaft and from there thrown out and carried by air currents into the rotating element.

To prevent action similar to that just described, an oil guard is cast in the upper half of the bearing extending below the bearing split and enclosing the oil ring. The housing walls are made straight, or at right

FIG. 12—A MODERN TYPE OF PILLOW BLOCK SHOWING BEARING AND OIL RINGS

angles to the oil surface, making a complete baffle at that point. This guard over the ring and vertical side wall is shown in Fig. 7. At the journal shoulder with the end play open and the journal running, the oil between the bearing and the journal shoulder is revolving in spiral lines. When the end play closes these lines loop and shoot out drops of oil parallel with the shaft. This spraying parallel with the shaft can be caught and returned to the oil cellar by an oil thrower on the shaft, surrounded by an oil guard, as shown in Fig. 11. This is an effective arrangement but is a refinement hardly necessary for small or medium sized bearings, the loose guard being therefore used only on large bearings. For bearings of small or medium size the oil thrower is turned in the shaft. To prevent the end action of the oil, as shown in Fig. 11, the oil delivery to the shoulder is cut down by means of a groove in the bearing opening into the oil cellar. This

is also shown in Fig. 13, which also exhibits two of the different types of end protection used.

As an example of efficient oil protection may be mentioned a 25 inch water cooled bearing used daily in rolling mill work which holds about three barrels of oil, with a shaft making 150 to 175 revolutions per minute, and which today uses the oil put in at the time of installation about six years ago. The oil is taken out occasionally, filtered, and put into use again. The bearing gives no indication of creeping oil, and both the shaft and bearing at the split are bone dry.

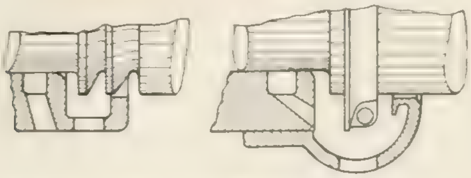


FIG. 13—TYPES OF END PROTECTION FROM OIL

BEARING LOSSES AND TEMPERATURE

Bearing losses are dissipated by methods similar to that used on electrical apparatus, usually by radiation and sometimes, when necessary, by means of oil or water circulation. The highest temperature is at a point slightly below the point of entrance, but as it requires special drilling for both bearing sleeve and housing and is a point rather difficult of access, especially for a thermometer, this temperature is seldom taken except for purposes of research. For a horizontal bearing the temperature rise, when given, means the temperature taken when running at the bearing shell near the oil ring.

Bearings 14 inches in diameter and larger are usually provided with water circulation, as shown in Fig. 14. At lower speeds the water circulation may not be necessary. The bearing may be kept within reasonable temperature limits by means of surface radiation only, but if particles of dirt or scale accumulate at the entrance they may cut off part of the oil supply or get into the film. If this occurs the water does not allow the temperature to rise high enough to fuse the babbitt. The particles are forced out and the bearing usually recovers itself without serious damage other than a few scratch marks. Water cooling also serves as a protection during the instant of starting or stopping, when the oil film is broken and there is in consequence a momentary high coefficient of friction.

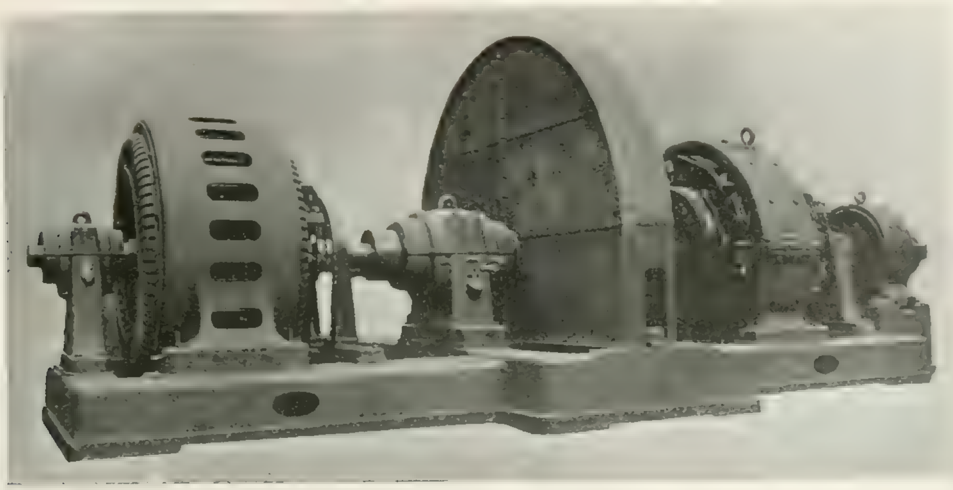


FIG. 14—FLYWHEEL MINE HOISTING SET
Showing method of piping oil and water to large center bearing

Application of Motors to Hardinge Mills

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In the various ore dressing plants producing copper concentrates, tube mills have lately been extensively introduced for the regrinding of the middlings or small particles of rock containing considerable copper. The machines used for the purpose are of several different designs, the favorite in the Michigan copper country being the Hardinge style. These mills were originally designed for belt-driving, the mill itself being fitted with a cast spur gear meshing into a cast pinion, the pinion shaft also carrying a belt pulley. The gear reduction on these mills was approximately seven to one.

About two years ago several of the companies in the Michigan district decided to add largely to their regrinding equipment. The Copper Range Consolidated Company installed 44 Hardinge machines in their stamp mills, 28 being eight feet in diameter, and 16 six feet in diameter. In installing these machines it was found considerably cheaper to use individual motor-drive, rather than to install shafting and large motors for group belt driving. There was also an advantage in having a motor for each separate unit both for operation and repair, and a material saving in power, due to the elimination of all shafting and belts.

Although it had been long known that the power demand for an eight-foot mill having a 30-inch cylindrical section was approximately 50 horse-power, to be sure of obtaining ample starting torque, the few motor-driven mills in operation had been supplied with 75 horse-power squirrel-cage motors fitted with the usual apparatus for starting at reduced voltage. As this method of operation was productive of a lower power-factor than desirable and as the starting torque of the mills from actual experiment was so near that of the full-load running torque, the experiment was made of substituting a 50 horse-power squirrel-cage motor for the regular 75 horse-power size and starting up this smaller motor under full voltage. This was carried out at the stamp mill of the Winona Copper Company and proved so satisfactory that it has become the standard method of starting tube mill motors in this district.

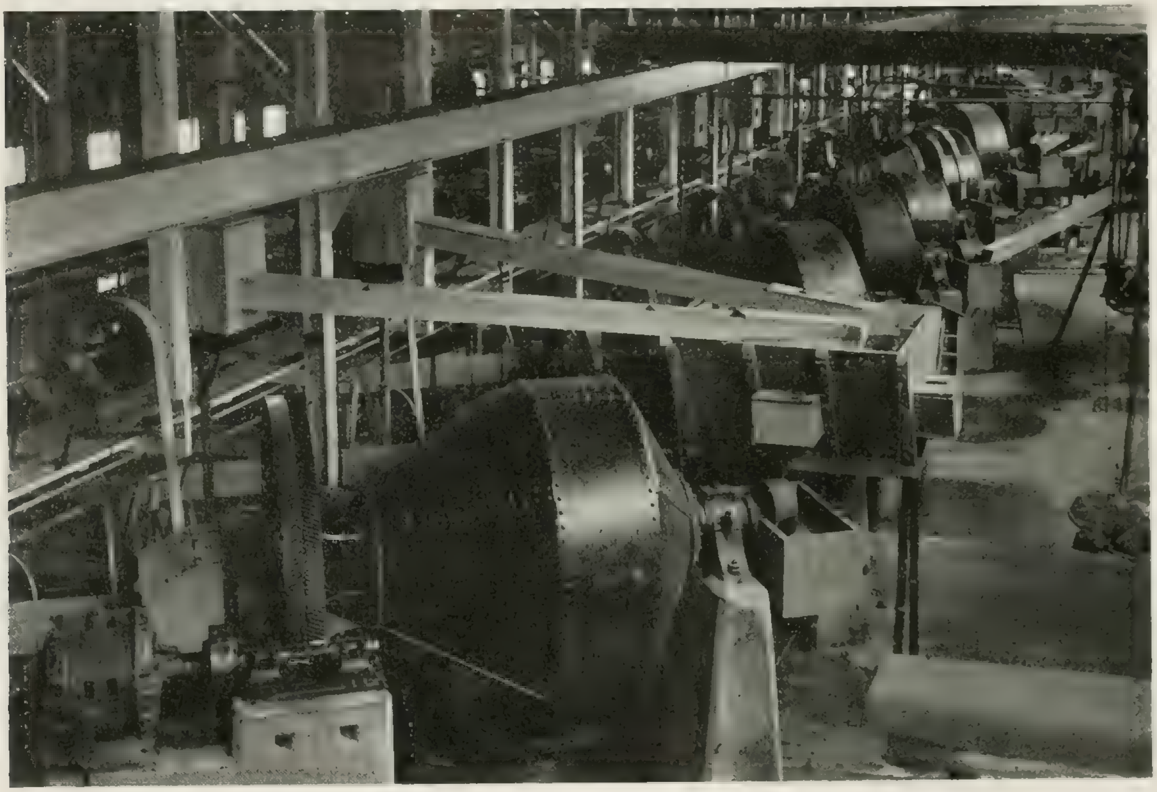

FIG. 1 HARDINGE MILL INSTALLATION SHOWING ARRANGEMENT OF MILLS AND MOTOR DRIVE

The mills as installed by the Copper Range Company were redesigned and built in their own shops, cut steel herringbone gears having a speed reduction of 18.7 to one being substituted for the cast spur gears used in the initial installation. Connection between the motor and pinion shaft was made by a flexible coupling. The motors used were of the Westinghouse *CS* type having interchangeable split bearing brackets and bearing shells. Both sizes of motors have the same diameter of shaft, and both sizes are wound for 14 poles, which materially reduces the number of spare parts necessary to carry in stock for repairs.

The power supply is three-phase, 60 cycle, 2 200 volts. All motors have open slots and form-wound impregnated coils, the ends of the coils being securely fastened to a steel ring to diminish vibration due to excessive starting currents.

In wiring up the stamp mills for these installations, wherever possible the current was carried on insulated bus-bars through the building, near or on the ceiling, the taps to the individual motors being three core wire armored cable. Varnished cambric insulation for 5 000 volts is used throughout. Where it was necessary to remove the armor for taps or splices, after insulating the conductors, they were served with a taping of sheet lead which was electrically connected to the grounded armor of the cable. For controlling the individual motors a three-pole single-throw oil switch having series overload coils and low voltage release was mounted on each motor foundation or on the adjacent columns; where the switch was mounted on concrete its frame was thoroughly grounded as were all the motor frames. The full-load current of the 50 horse-power motors being about 13 amperes and

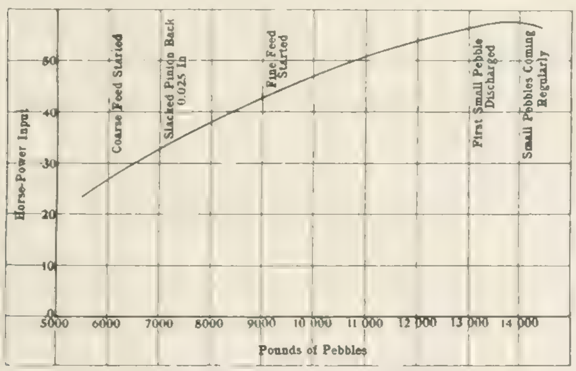

FIG. 2—TEST ON AN EIGHT FOOT HARDINGE MILL.

the starting current 90 amperes made it difficult to adjust the dashpots on the series coils of the oil switches, to give protection during normal operation and not to operate during the period of starting. The dashpots were finally made inoperative and fiber finger pieces attached to their stems to allow manual holding in of the switch during the period of acceleration.

The larger mill weighs empty about ten tons; the charge of pebbles, sand and water approximately the same. The period of acceleration of this mass is approximately four seconds, and during two years of operation under these conditions there have been no failures of motors or switches chargeable to this method of starting. Where it was necessary to install new shafting for driving concentrating tables and centrifugal sand pumps, this was also motor driven, using 50 horse-power motors which had the same starting equipment as did the tube mill motors.

The Copper Range stamp mills are three in number located on the shore of Lake Superior, and are spaced from one to one and a half miles apart. The total number of motors installed in the three mills is thirty-one 50 hp and eighteen 25 hp of which approximately 1 600 hp are in operation at one time. These are started up about noon Monday and run continuously until the next Sunday morning.

For the power supply, a 1 500 k.v.a. low pressure steam turbine was installed in the stamp mill at Redridge, where there were available between 40 000 and 45 000 pounds of exhaust steam per hour, from the operation of six steam stamps and one compound engine; the turbine being also supplied with a connection for high pressure steam. The exhaust from the turbine passes to an 8 750 square foot single-pass surface condenser having tubes one inch in diameter by 16 feet 10 inches long. The circulating water consists of the water subsequently used in the stamp mill, amounting to about 12 000 gallons per minute; it flows through the condenser under a gravity head varying from 12 to 20 feet, the friction loss in the tubes being less than two feet. As the vertical distance from the under side of the condenser to the basement floor was 35 feet, the condensate was handled through barometric legs of wrought iron pipe discharging into a concrete hot well in the basement, making a condensate pump unnecessary. Air and other non-condensible gases are extracted by a steam-driven dry air pump having a 30-inch by 18-inch stroke air cylinder. This installation operates continuously with a vacuum of 29 inches, referred to a 30-inch barometer, and is handled by one man on each shift, who is also in charge of the switchboard. This is of the usual self-contained type having oil switches mounted on the backs of the panels, and consists of one generator and four feeder panels. The voltage is controlled by a Tirrill regulator which operates either on the motor-driven exciter or on the one direct-connected to the turbine. Two feeder panels control some 600 hp of motors in this mill; a third one supplies current for the motor-driven exciter, mill and town lighting, and the fourth panel feeds a 1 500 kw sub-station where the voltage is stepped up to 30 000 for transmission to the other two stamp mills and eventually some 15 miles to the mines.

All three sub-stations are alike and built of concrete block. They have concrete floors and reinforced concrete tile roofs laid on steel purlins. Each substation has a 1 500 kw equipment of transformers to take care of the future installation of a turbo-alternator of similar capacity. All switching is done on the low-tension side of the transformers; knife-blade disconnecting switches only being used on the high-tension wires. Each sub-station has the usual electrolytic lightning arresters on the 30 000 volt side; one also being equipped with low equivalent arresters on the low-tension side, it having a considerable amount of exposed line wire.

The high-tension line is of No. 2 B. & S. hard drawn solid copper. Poles are Tripartite steel, spaced 300 feet apart and are set in concrete; the average height being 35 feet from the ground to the top of

the pole. The cross arms are steel angles, arranged to carry three wires on each side of the pole in a 42-inch delta. A galvanized iron plate two feet square and one-quarter inch thick having a No. 2 B. & S. copper wire riveted and soldered to it was put in the bottom of each pole, the wire leading up through the concrete and clamped under one of the bolts of the pole above the ground.

A No. 30 B. W. G. solid galvanized steel ground wire is clamped to the top of each pole; 40 000 volt porcelain insulators supported on steel pins are used for the line wires which are held on the insulators by clamps. At all corners the line wires are dead-ended on one 16-foot double steel cross arm supported by two poles, having head, back and side guys. The ends of the line wires, after being attached to the strain insulators, are carried over the cross-arm, supported by pin type insulators, and are connected by cast copper clamps to facilitate the opening of the line wires for testing.

The Engineering Evolution of Electrical Apparatus—V

THE EVOLUTION OF THE POLYPHASE INDUCTION MOTOR

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THE history of the polyphase induction motor dates back to a period between 1885 and 1888, when Nicola Tesla and Galileo Ferraris independently conceived the ideas involving its fundamental principles. These fundamental principles, briefly stated, are: First, that a magnet moving over a conducting plate or surface exerts a pull on that plate or surface; second, that polyphase alternating currents distributed in a certain definite manner over a magnetic structure produce the same magnetic effect as a mechanically moved magnetic field.

In the early motors which Tesla devised, adjacent poles around a polar crown were excited by currents successively displaced in phase so as to produce the effect of a rotating or progressive magnetic field. An armature placed in a field thus formed was provided with windings closed upon themselves in order that secondary currents might be induced in them which would exert a pull the same as when a magnet is moved across a conducting plate.

The theory of the magnetic rotating field, as exemplified by the first Tesla motor, has been exhaustively treated in many electrical text-books written within the past twenty years until now it is a matter of common knowledge and therefore needs no further mention in an article whose scope is necessarily limited, as is the case with the present one. The fundamental principles of the induction motor appear in all of the different types of the machines which have been developed since the first one was produced by the earliest inventor. All of the developments and improvements which have taken place in the motor have been along the lines of perfecting the electric and magnetic characteristics of the motor circuits. In the early days when the induction motor was in the development stage, the fundamental principles of the electric and magnetic circuits, especially those used in connection with alternating currents were not well understood, and the partial failure of the early Tesla motors may be said to have been due almost entirely to the lack of knowledge of the electric and magnetic conditions as they are understood to-day.

FIG. 1—A GROUP OF EARLY TESLA MOTORS (BEFORE 1890.)

Note the construction of the secondaries. The primaries of these early motors were of the polar type as shown diagrammatically in Fig. 4.

The Tesla motors built from 1888 to 1890, as shown in Figs. 1, 2 and 3, were in general appearance quite similar to the polyphase induction motors of to-day.

The primary was stationary and formed of laminated iron, and quite frequently was of the frameless type of construction. The primary winding, however, instead of being distributed as in modern motors, was of the polar type, as shown in Fig. 4. There were twice as many polar projections as actual magnetic

poles in the machine. Each pole carried a coil and coils on alternate poles were connected together and across one phase, the machines in general being built for two-phase circuits. The secondary core of these early induction motors was, in nearly all cases, of the slotted construction and carried group windings, as indicated in Fig. 4. The groups of the different phases overlapped each other very much as in the present distributed primary windings. In addition to this, the groups of each phase were either separately, or collectively, short-circuited on themselves. In many cases an extra or idle slot was used in the secondary to make the number of secondary slots prime to the number of primary poles, in order to reduce the tendency towards "dead points," or points of lower torque than the average; in fact, the distribution of the secondary winding was carried so far that attempts were made to arrange the number of conductors in each slot with the view of providing the smoothest torque conditions.

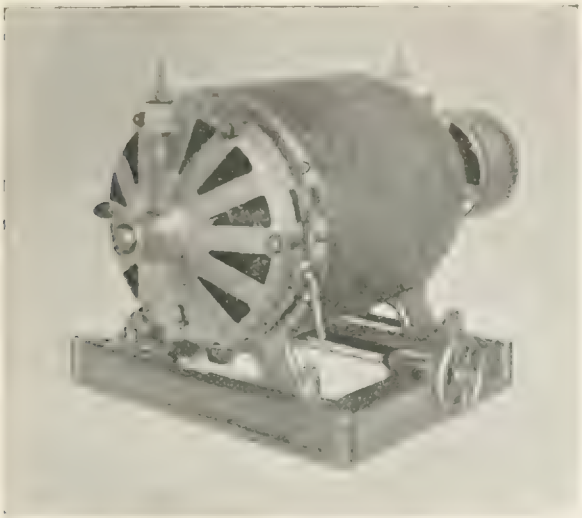

FIG. 2—TESLA MOTOR, PERIOD 1888-1890

Note the frameless construction with primary laminations riveted together. Compare with the frameless construction of to-day, Fig. 25.

FIG. 3—ONE OF THE EARLIEST APPLICATIONS OF TESLA'S INDUCTION MOTOR

About 1889 or 1890 a number of motors of this early type were built and put into commercial service; they required for their operation a polyphase circuit which necessitated the building of a special generator. This generator, in addition to being polyphase, had to be compounded to take care of the inductive load imposed upon it by the motor and therefore the whole plant was highly special and experimental. The fact that the polyphase induction motor required a polyphase circuit for its operation and that there were at the time of its introduction no such systems in general use, naturally handicapped the motor from a commercial standpoint. At that time the only commercial supply circuits were single phase of 15 000 to 16 000 alternations per minute (125 to 133 cycles per second). This frequency in itself was practically prohibitive so far as induction motor operation was concerned and therefore acted as a further handicap. The fact that the induction motor did not come into general use until a number of years after was due not to any serious shortcomings of the motor itself, for, in reality, some of the earlier motors had quite good operating characteristics, but to the lack of satisfactory supply circuits.

It will be remembered that the early nineties was a period of financial stress. During this period development work was greatly retarded. However, in the year 1892 the Company again took up in an experimental way the development of the polyphase induction motor, but along somewhat different lines. By this time the theory of magnetic proportions and magnetic flux distributions had been more fully developed, especially in connection with the design of alternating and direct-current generators of the slotted armature types. In analyzing the design of the first commercial Tesla motors in the light of the experience gained from later generator designs, the engineers of the Company quickly recognized its inherent weaknesses and saw that the polar primary or field construction was uneconomical and an unsatisfactory arrangement from a magnetic standpoint. Following this analysis, it was decided to build an experimental motor with well-distributed primary and secondary windings, the primary being practically the same as is found on the induction motor of to-day. This experimental motor was subjected to exhaustive tests, using various combinations of the secondary windings, from individually short-circuited groups to complete short-circuits of the entire mass of the end windings, thus forming in effect the so-called squirrel cage winding. The superiority of this experimental motor from a magnetic standpoint over that with the polar type of primary,

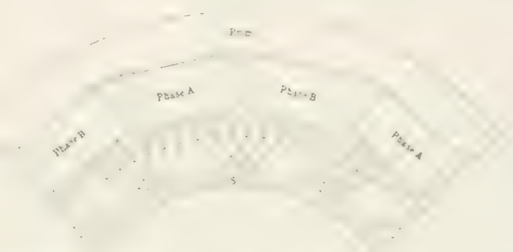

FIG. 4—SKETCH OF POLAR PRIMARY AND SLOTTED SECONDARY OF THE EARLY TESLA MOTOR

(See rotor at left in Fig. 1.)

definitely settled the direction along which future development of the induction motor should proceed.

The further development of the polyphase induction motor would have been of little avail under existing handicaps imposed by the single-phase high frequency supply circuits. This situation was early recognized as a controlling element in the development but, fortunately, since 1890 a decided move had been started toward the use for distributing service of frequencies lower than 133 cycles per second, as the high frequencies were found to be poorly adapted to engine-type alternator construction, arc lamp service, etc. Following this move, a campaign was launched in favor of polyphase generators for distributing service, partly with the idea that if suitable supply circuits were available, there would eventually be created a demand for induction motors to operate on such circuits. It is of interest to note that this campaign was quite successful, and that between 1892 and 1895 a strong sentiment was created in favor of polyphase generators; in fact, so much so that a demand for polyphase induction motors actually developed by the time the motors were perfected and ready for the market.

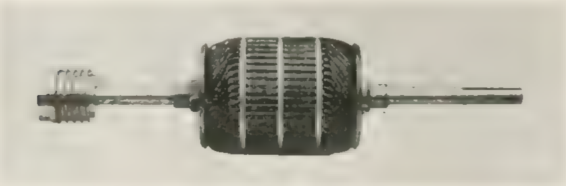

FIG. 5—ROTATING PRIMARY OF TYPE B POLYPHASE INDUCTION MOTOR—PERIOD 1893-1897

Encouraged by the satisfactory results obtained from the experimental induction motor with distributed windings, described above, and confident of the future of such a motor, the Westinghouse Company authorized the design and development of a commercial line of moderate capacity induction motors, later known as type "B." Although the experimental motor was of the rotating secondary type, this arrangement was followed only in motors up to and including the five horse-power. In these small motors, the rotating secondary was of the squirrel cage type, similar to the secondary of present day motors. In sizes above five horse-power the new line was made with rotating primary, Fig. 5, as it was found that this arrangement would lend itself more readily to a satisfactory construction of the secondary winding. The stator of the new motor consisted of a cast iron yoke enclosing a laminated secondary core with partially closed slots. The winding was of the so-called bar type, one bar per slot, with end connectors bolted on or soldered and forming a two circuit closed coil arrangement, the same as the well known two circuit direct-current armature winding. This winding was tapped at a number of points and leads from the taps were closed on each other through resistors. On the frame of the motor a switch was provided to short-circuit these resistors after the motor had been started and allowed to attain nearly normal speed, Fig. 6. With this secondary construction, composed of a relatively small number of heavy bars, the secondary voltage was obviously low, and the secondary current correspondingly high. It was considered inadvisable to use such a construction on a rotating secondary on account of the size and cost of the collectors and brush-holder rigging required, and the resistance this arrangement would add to the secondary circuit. Hence the choice of the rotating primary with low current in the collectors.

The first induction motors of this new line had the secondary windings tapped to resistors at four points, electrically 90 degrees apart. Later, however, this was changed to six or eight points following a series of tests to determine the effect on the maximum pull-out torque of different numbers of secondary phases. These tests were made first with the secondary winding short-circuited at three points electrically 120 degrees apart; second at four points 90 degrees apart; third, at six points 60 degrees apart; and so on until the entire winding was short-circuited on itself with the maximum possible number of connectors. These tests showed conclusively a decided improvement in maximum torque as the number of tapped points was increased up to twelve. Beyond this the increase was not marked. However, six taps were found to be decidedly better than four, and twelve better than six, though to a less extent. Quite a number of commercial machines of this line were made with six and eight secondary taps.

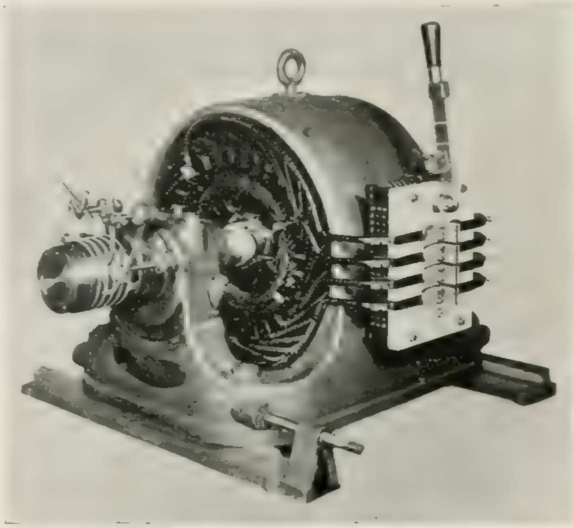

FIG. 6—TYPE B POLYPHASE INDUCTION MOTOR

Showing switch on side of the frame for cutting out resistance in secondary circuit after motor has attained normal speed. Note the heavy bar and end-connector windings of the stationary secondary.

In a later development of the type "B" motor, the secondary winding was provided with a large number of cast iron grids or resistors, connected between adjacent turns, with a circular ring, or switch, for short-circuiting the winding at many points. This arrangement is shown in Figs. 7 and 8. The resist-

ance grids were bolted directly to the armature winding. They were of cast iron of comparatively heavy section and high heat storage capacity. Motors of this type were constructed in capacities up to 200 and 300 horse-power, for both 25 and 60 cycles, high and low voltage.

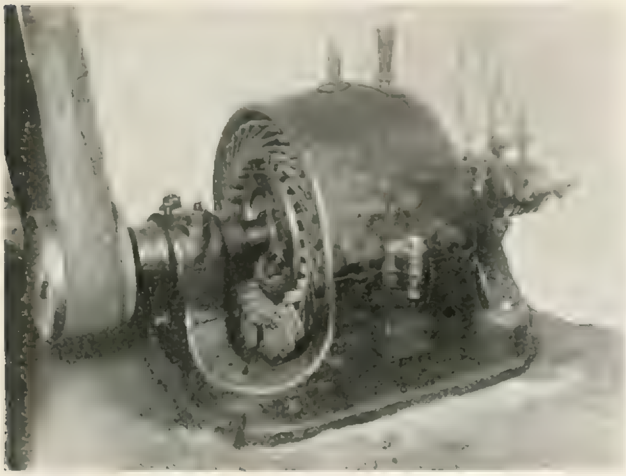

FIG. 7—A LATER TYPE B MOTOR

Showing grid resistors bolted to the ends of secondary bar windings. This motor was shipped to the customer May 11th, 1896, and has been in active daily service ever since. It was shut down for a few moments on May 29th, 1914, in order that this photograph might be taken.

The type "B" motor was manufactured commercially and very widely distributed up to the year 1897. That it was an eminently satisfactory motor, and a credit to its designers, is attested by the fact that there are many of the motors operating to-day after more than seventeen years of continuous service. One plant, within the writer's knowledge, has fifteen of these motors now in daily operation, and with the best prospects of continuing to run for a number of years to come.

The Westinghouse type "C" polyphase induction motor, with rotating squirrel cage secondary, followed the type "B" motor. The design of the motor was suggested by the results obtained from the tests of some high torque induction motors for crane service. In these high torque motors absolute simplicity was required. It was desired to eliminate all slip rings, external secondary resistors and short-circuiting devices. A study was accordingly made of the fundamental characteristics of the squirrel cage type of secondary winding, as this construction appeared to be ideal for the service, if the secondary regulating devices could be omitted. This study led to the construction of an experimental motor with rotating squirrel cage secondary, in which the self-induction was low and the slip relatively high, so that the maximum torque was developed at a slip of 100 percent. The self-induction being low, it was possible to make the maximum torque several times full-load torque. This motor demonstrated conclusively that it was feasible to construct squirrel cage induction motors with a starting torque several times normal full-load torque and, with such characteristics, it proved to be entirely practicable to control the speed by varying the primary voltage. Many motors of this construction were afterward manufactured and used in crane, elevator and other intermittent varying speed service.

Following the development of this high torque motor, the characteristics of the type were made the subject of continuous study and investigation by the engineers of the Company as the simplicity of the construction appealed to all, and it was recognized that it would be the ideal design for induction motors for general service. The elimination of slip rings and starting devices on a general service motor would at once broaden its field of application, as it could be located in more or less inaccessible places and, in general, installed to better advantage, as it would require little or no attention other than to see that the oil in the self-oiling bearings was occasionally renewed.

It was soon demonstrated that a constant speed motor could be designed along the general lines of the high torque motor with a slip of three or four percent at normal load, which would give secondary losses that could be dissipated easily in the secondary winding without overheating. It was further found that a motor could be made which would have a starting torque several times full-load torque with normal voltage applied to the primary. Under these conditions of slip and starting torque the line current required at start was six to eight times normal full-load current,

FIG. 8—COLLECTOR END OF A MOTOR OF THE TYPE SHOWN IN FIG. 5

Showing circular switch for short-circuiting the secondary windings after the motor has attained normal speed.

which was more than commercial circuits would permit. However, as most applications required less than full-load starting torque, it was feasible to reduce the primary voltage at start to a point just sufficient to give the requisite starting torque. By the use of an auto-transformer to thus reduce the primary voltage.

both the maximum line current and maximum starting torque were proportionally reduced to suit the individual requirements. This marks the beginning of the well known Westinghouse type "C" motor and auto-starter, Figs. 9 and 10. In the light of the experience with induction motor design, and the rather hazy

FIG. 9—TYPE C POLYPHASE INDUCTION MOTOR PERIOD 1897 TO 1905

understanding of its theory by the electrical fraternity at that time, the introduction of this motor was viewed as a very radical step. The general impression existed that of necessity a cage-wound-secondary motor had a very low starting torque and that, therefore, the combination of an auto-transformer with it to *reduce* the starting torque bordered on the absurd. The particular feature of the design which permitted the accomplishment of this apparently absurd result was the proper proportioning of the self-induction so that the starting torque was much larger than full-load torque The first technical description of the Westinghouse type "C" motor and its underlying principles appeared in a paper presented at the twentieth convention of the National Electric Light Association at Niagara Falls, June 10, 1897.* This paper is a technical classic and stands to-day, seventeen years after it was published, as the simplest and best exposition of the subject that has ever been written.

The type "C" polyphase induction motor embodied in its design practically all of the essential features found in later induction motors. In all sizes up to 300 horse-power the stationary primary was formed of a solid cast-iron yoke enclosing a laminated core with open slots. Above this size the cast-iron yoke was split horizontally and machined to carry a solid cast-iron ring, Fig. 11, containing the laminated core. The windings of motors of small and moderate size were composed of form-wound coils, completely insulated before being placed in the slots and arranged two layers deep as in most of the modern motors. In the larger sizes of motors, the low voltage windings were often of the bar and end-connector type. The secondary, Fig. 12, was formed of a cast-iron spider carrying a laminated core with partially closed slots, the number of slots being usually prime to the number of stator slots, to lessen the tendency to points of low torque in starting. The secondary windings consisted of rectangular copper bars connected to end rings of copper or of some non-magnetic alloy of higher resistance. In motors where high starting torque was required, the alloy used was from twenty to forty times the resistance of copper. Iron was tried for the resistance material, and while it gave a good shape to the speed-torque curve, it materially lessened the maximum torque developed and was therefore not adopted.

It is interesting to note that one of the principal problems in the development of the first type "C" motor was a mechanical one, due to the difficulty of maintaining a secure connection between secondary bars and end rings. Copper rivets could not be used with copper bars and rings because they were not of sufficient strength and would stretch and loosen due to the pull of the ends of the bars by centrifugal action. Iron rivets or bolts alone could not be used because they stretched and loosened also, due to the unequal expansion of the materials as the end rings heated under the starting conditions. Soldered connections could not be maintained on account of overheating under starting conditions. One of the first motors built for crane service had the bars bolted to the end

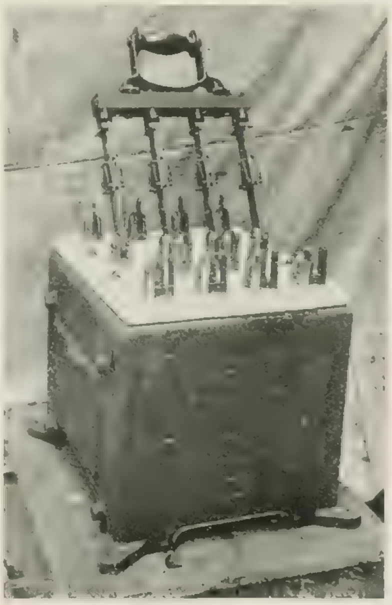

FIG. 10—AIR BREAK AUTO-STARTER USED WITH EARLY TYPE C MOTOR

rings. In an endurance test made on it, where it was loaded repeatedly till it dropped to zero speed, it was found that over half of the bolts had loosened and some had actually developed cracks. The situation appeared very serious until finally one of the engineers

*"The Polyphase Motor," by Mr. B. G. Lamme, chief engineer, Westinghouse Electric & Mfg. Company.

on test suggested using lock washers of the spring type, not to lock the nuts, but to give a cushioning or spring effect between nuts and rings. The suggestion was tried and proved entirely successful and, although there are now several other methods of making this

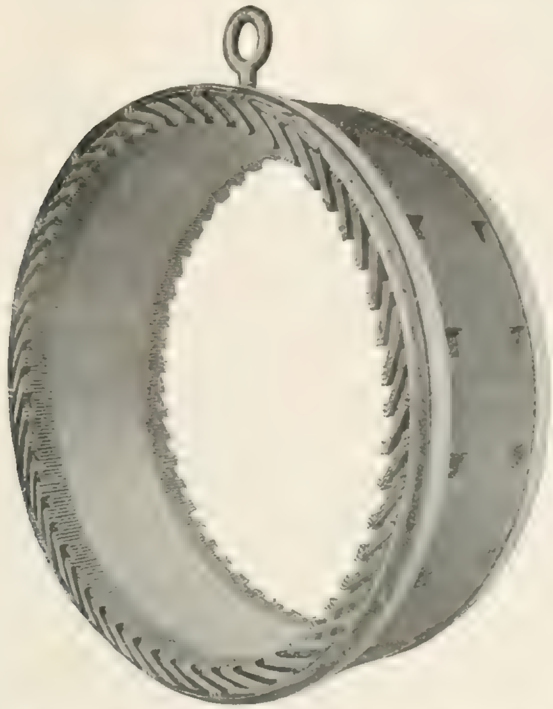

FIG. 11—PRIMARY RING OF LARGE TYPE C POLYPHASE INDUCTION MOTORS

Note the bar and end-connector windings and partially closed slots.

connection, such as welding or casting the ring to the bars, still the original bolt and spring washer construction is used to-day very extensively by all manufacturers of induction motors. The function of the spring washer had to be understood by the workmen in the factory and the repair shop, otherwise its purpose was defeated by tightening the bolt until the washer was flattened out and no margin left for expansion. It was difficult at first to get the manufacturing departments to appreciate this point.

The success of the type "C" induction motor as originally designed was phenomenal. It probably did more to popularize motor-drive than any other line of motors ever placed on the market. It was conceded by all users to be "as simple and rugged as a grindstone." Its liberal design, large factors of safety, overload capacity and excellent electrical characteristics won for it a reputation that has seldom been equaled.

As an induction motor is essentially a constant speed machine, its field was at first limited to applications similar to those where shunt-wound direct-current motors are used. The desirability of extending its field to other applications, such as were covered by the direct-current varying speed, adjustable-speed and compound wound motors, was early recognized and, although the motor was not inherently adapted to all such applications, it was nevertheless modified in design so as to be satisfactory for many of them. The first varying speed application was that for the operation of cranes, which was effected by the use of high resistance rotor end rings and primary windings of low self-induction, adapted for giving high maximum torque, as has been previously noted. The use of such a motor for varying speeds, however, had rather narrow limitations on account of the difficulty in dissipating the heat generated in its resistance rings. In order to be satisfactory the service for such a motor had to be intermittent, and with sufficient intervals of rest between operations or with sufficient periods of light loading to prevent excessive heating of the resistance rings.

Another interesting modification of the early type "C" motor was the polyphase multispeed type. The first installation by the Westinghouse Company of this type was made in 1899 when a special motor was developed for the Silver Springs Bleaching and Dyeing Company of Providence, Rhode Island. This was a three-phase, 25 cycle, 220 volt motor and had three separate primary windings adapted for 4, 8 and 12 poles, the ratings on the three windings being 30, 15 and 10 horse-power respectively. These windings were placed in deep open slots in the usual manner, the 4-pole winding being at the bottom of the slots, the 8-pole in the middle and the 12-pole at the top. This arrangement, it will be noted, favored the slower speed windings which inherently had comparatively high self-induction, by locating them in the slots nearer the air-gap, thus minimizing the slot leakage. The secondary winding consisted of a single squirrel cage with the resistance rings proportioned to give the best compromise for the three different primaries. The construction of this motor was expensive on account of the three separate windings, two of which were idle all the time. Later developments in the multispeed motor were confined almost entirely to

[illegible]

Showing the method of bolting bars to end rings, using spring washers under nuts of bolts.

two-speed constructions using a single primary winding with external taps arranged for changing the number of poles. The ratio of the speeds of these motors was usually two to one, although some three to four combinations have been developed.

(To be continued)

The Situation Before the Cotton Textile Manufacturers

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The cotton textile manufacturers are the only manufacturers who, in the past decade, have succeeded in increasing the earning power of their capital, by increasing their production faster than they increased the capital. In other industries, such as tanneries, woodworking plants, foundries and machine shops, manufacturing iron and steel, and bituminous coal mining, the capital has increased faster than the production. A comparison of the leading industries with the textile industry is shown in Table I, giving the value of the products on a basis of $100 capital.

TABLE I—SUMMARY OF LEADING INDUSTRIES—VALUES OF PRODUCTS PER $100 CAPITAL

Item	1900	1910	Percent. change in 10 years
Textile	$ 72.50	$ 76.42	5.3
Foundry and Machine Shop	100.97	81.12	19.8—
Tannery	117.28	101.32	15.7—
Tin Plate	179.57	136.29	9.0—
Blast Furnaces	144.42	80.28	44.5—
Steel Works and Rolling Mills	138.81	98.10	29.5—
	1902	1909	
Coal Mines	66.72	38.10	42.0—

The cotton textile industry of the United States is growing wonderfully fast, as shown in Table II, which gives the value of the production and the percent increase per decade for the past 50 years. A greater quantity of cotton goods is produced in this country than in any other except Great Britain. The average increase per decade since 1860 is 42.2 percent. This figure may not sound large, but when it is considered that the amount of money involved runs into the hundreds of millions of dollars, it is astounding. It is reasonable to assume that this figure will hold good for 1920, in which event the value of the products will be approximately $894 000 000. The value of the products since 1860 is graphically shown in Fig. 2. The dotted line indicates the writer's estimate for 1920. Comparing this with the past performances, the estimate seems entirely probable.

TABLE II—VALUE OF PRODUCTS IN THE COTTON INDUSTRY

Year	Value per Decade	Percent. Increase per Decade
1860	$115 681 000	...
1870	177 489 000	53
1880	192 090 000	8
1890	267 981 000	39
1900	339 200 000	26
1910	628 392 000	85

The present situation before the cotton textile manufacturers can be shown best by analyzing the data contained in the United States census reports. Tables III, IV, V and VI show:—

a—The size and progress of this business as an industry.
b—The conditions and the amount of business done by the average establishment.
c—The cost to manufacture per $100 worth of goods produced.
d—The value of the product, its cost and the profits per $100 capital invested.

Table III gives the total number or value for all establishments; it also shows the growth since 1900. That there was a considerable increase in competition in the past decade is indicated by the item marked "Number of Establishments," which increased 23 percent. It is interesting to note that the capital increased 75 percent and the primary horse-power 63 percent. The latter figure indicates that the greater part of the new capital was spent for new equipment. New machinery was installed, to operate which required greater power plant capacity; furthermore, new buildings were needed to house this apparatus. Wages and salaries increased faster than the number of wage earners and salaried employees, showing that the average individual receives a larger compensation than formerly.

TABLE III—TOTAL VALUE OR NUMBER FOR ALL ESTABLISHMENTS

No.	Item	1900	1910	Percent change in 10 years
1	Capital	$467 240 000	$822 228 000	75.0 +
2	Primary horsepower	799 804	1 296 517	63.0 +
3	Number of establishments	1055	1324	25.6 +
4	Salaried employees	4902	8414	71.7 +
5	Number of wage earners	302 861	378 880	25.2 +
6	Value of products	$339 200 000	$628 392 000	85.2 +
7	Cost of materials	176 552 000	371 009 000	100.0
8	Wages	86 690 000	132 859 000	53.3 +
9	Salaries	7 350 000	14 412 000	96.0
10	Miscellaneous expenses	21 650 144	36 030 000	20.2
11	Cost of manufacturing	292 242 141	554 310 000	89.6
12	Gross profits	46 957 856	74 082 000	68.0 +
13	Percent. profit on capital	10.05	9.0	11.7 —
14	Average wage per wage earner	$286.24	$350.66	22.0 +
15	Average salary per salaried Employee	$1499.38	$1692.61	13.0 +

In order to give a better idea of the condition and the progress made by the average mill, Table IV is given, being an analysis of Table III, with the details worked out upon the number or value per establishment basis. Of course, the figures in dollars and cents will apply in but few cases but the percentages will apply to most mills. One feature of interest brought out in this table is the ratio of production to the number of employees. So many cotton manufacturers bewail the fact that they have to pay so much more for

TABLE IV—TOTAL VALUE OR NUMBER PER ESTABLISHMENT

No	Item	1900	1910	Percent change in ten years
1	Capital	$442 881	$621 018	28.6
2	Primary horse-power	754	979	29.9 +
3	Number salaried employees	4.6	6.4	30.1 +
4	Number wage earners	287	276	0.35 —
5	Value of products	$321 516	$474 616	78.8 +
6	Cost of materials	167 348	280 218	67.0 +
7	Wages	82 170	100 346	22.0 +
8	Salaries	6 966	10 885	56.0 +
9	Miscellaneous expenses	20 521	27 213	33.2 +
10	Cost of manufacturing	277 005	418 663	51.0 +
11	Gross profit	44 511	55 953	26.6 +
12	Percent. profit on capital	10.05	9.0	10.5 —

labor. Although this is so when applied to the individual workman, the total number of wage earners decreased while the value of the product increased 78.8 percent. If it had not been for the use of more efficient machinery and more intelligent labor the number

TABLE V—TOTAL VALUE OR NUMBER PER $100 VALUE OF PRODUCT

No	Item	1900	1910	Percent change in ten years
1	Capital	$137.16	$130.85	4.8 —
2	Primary horse-power	.23[illegible]	.204	12.7 —
3	Number salaried employees	.0015	.0014	7.1 —
4	Number of wage earners	.081	.061	[illegible]
5	Cost of materials	$52.[illegible]	$59.04	13.4 +
6	Wages	25.[illegible]4	21.14	20.8 —
7	Salaries	2.16	2.29	6.0
8	Miscellaneous expenses	6.38	5.73	11.[illegible] —
9	Cost of manufacturing	86.13	88.20	2.4
10	Gross Profits	13.87	11.80	17.5 —

of wage earners would have increased in direct proportion to the production. The increased complication of the business, requiring a larger office force, is proven by the increase of the number of salaried employees.

In Table V is shown the capital required, the total manufacturing costs, and the details of cost for each $100 worth of goods produced. The capital required is a most interesting item and shows the efficiency of manufacturing. To manufacture $100 worth of goods in 1900 required an investment of $137.16 and in 1910 an investment of $130.85, a decrease of 4.8 percent. This is a big step in the right direction. Another feature of especial interest is the item of wages. Although the average wage per individual increased 22 percent, nevertheless the manufacturers were able to reduce the total cost of wages 20.8 percent per $100 output. This again emphasizes the fact that more intelligent labor was employed and machinery of greater efficiency installed. The cost of materials increased 13.4 percent and salaries 6 percent. Even with the greater cost of these items the manufacturers were able to hold down the cost of production so that the total cost only increased 2.4 percent. This was because of the high standard of manufacturing efficiency maintained. Conversely Table VI gives the value of the product, the cost to manufacture and the gross earnings for each $100 capital invested. There was 10.05 percent profit earned upon the capital in 1900 and 9.02 percent in 1910. This is gross profit. The census figures do not include charges for depreciation, amortization, interest on capital or on money borrowed. If these fixed charges were deducted only a small profit would be left.

TABLE VI—VALUE OR NUMBER PER $100 CAPITAL

No.	Item	1900	1910	Percent. change in ten years
1	Value of products	$72.59	$76.42	5.3 +
2	Cost of materials	37.79	45.12	19.4 +
3	Wages	18.55	16.16	14.8 —
4	Salaries	1.57	1.75	11.4 +
5	Miscellaneous expenses	4.63	4.37	5.9 —
6	Cost of manufacturing	62.54	67.40	7.2 +
7	Gross Profit	10.05	9.02	10.5 —
8	Percent. profit on capital	10.05	9.02	10.5 —

THE PROBLEM

The foregoing paragraphs show that the net earnings of this industry are not as high as they should be. The question is how to increase them. The manufacturers cannot control the price of their raw ma-

FIG. 1—AN INSTALLATION OF FOUR HORSE-POWER [illegible] INDUCTION MOTORS

Direct-connected to Saco-Pettee spinning frames in the plant of the Chicopee Manufacturing Company.

terial or the selling price of their product. However, many of them can reduce their fixed charges and labor cost per unit of production by producing a greater output.

In the majority of mills there exists a splendid opportunity to increase production by studying the speed conditions and the application of power to the productive machinery; also economies can be effected in the method of generating and distributing power in the mill. In most mills, especially those with mechanical transmission, a study will show that the speed of the productive machinery is much below normal, which, of course, means a loss of production. The best way to illustrate this would be to cite the conditions that existed in one large mechanically driven mill. The case cited is by no means an exception; in fact the general conditions in this mill were a little better than is ordinarily found.

The following tests give the speeds of various types of machines in each department, the percent

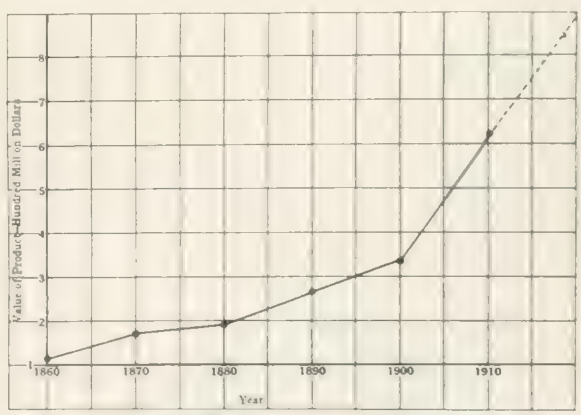


FIG. 2—CURVE SHOWING INCREASE IN THE VALUE OF PRODUCT OF THE COTTON TEXTILE INDUSTRY

speed at which they were operating and in some instances the effect of the low speed upon production. For the sake of brevity, only a partial list of the ma-

chinery in each department is given. The examples cited are representative of the conditions found throughout the mill. Where only one speed is given, the speed was constant. Where two speeds are given, a speed fluctuation is shown.

Test 1—(American Machinery Co.)—Hopper or Bale Opener.

Speed of beater shaft varied from 430 to 450 r.p.m., average 440 r.p.m. The speed of this shaft should be 575 r.p.m.; thus the machine is operating on an average of 23.5 percent under speed.

Test 2—(American Machinery Co.)—Pickers.

Speeds were taken from the beater shaft and found as follows:—

a—480 to 490 r.p.m.	f—460 to 470 r.p.m.
b—490 to 500 r.p.m.	g—470 to 475 r.p.m.
c—480 to 490 r.p.m.	h—475 r.p.m.
d—480 r.p.m.	i—475 to 480 r.p.m.
e—450 r.p.m.	

The mean average operating speed of these machines is 475 r.p.m. The correct operating speed should be 550 r.p.m. Thus these machines are operating at an average of 13.62 percent slow.

Test 3—(American Machinery Co.)—Intermediate Breakers.

Speeds were taken from the beater shaft and found as follows:—

a—1210 to 1220 r.p.m.
b—1200 r.p.m.
c—1200 to 1210 r.p.m.

The mean average speed of the above machines is 1 208 r.p.m. As the correct operating speeds should be 1 450 r.p.m., these machines are operating at an average 242 r.p.m. under speed or 16.7 percent slow.

Test 4 — (American Machinery Co.) — Intermediate Breakers.

Speeds were taken from the beater shaft.

a—1160 to 1170 r.p.m.	d—1170 to 1180 r.p.m.
b—1190 to 1200 r.p.m.	e—1120 to 1130 r.p.m.
c—1160 to 1170 r.p.m.	

The mean average speed of the above is 1 165 r.p.m. The speed of these machines should be 1 450 r.p.m.; thus they are operating 285 r.p.m. under speed or 19.65 percent slow on an average.

Test 5 — (American Machinery Co.) — Intermediate Breakers.

The speeds were taken from the beater shaft.

a—1190 to 1200 r.p.m.	c—1200 to 1210 r.p.m.
b—1190 to 1200 r.p.m.	d—1200 to 1220 r.p.m.

The average speed of the above is 1 201 r.p.m. The correct speed is 1 450 r.p.m.; thus these machines are operating 249 r.p.m. under speed or 17.3 percent slow on an average.

Test 6—(American Machinery Co.)—Lappers.

Speeds were taken from the beater shaft.

a—1150 to 1170 r.p.m.	c—1200 r.p.m.
b—1190 to 1200 r.p.m.	d—1180 to 1220 r.p.m.

The mean average speed of the above is 1 188 r.p.m. The correct speed of this beater shaft is 1 450 r.p.m.; thus these machines are operating 262 r.p.m. under speed or 17.4 percent slow on an average.

Test 7—(Ashworth Bros.)—Carding Machines.

a—172 r.p.m.	e—182 r.p.m.
b—174 r.p.m.	f—158 r.p.m.
c—176 r.p.m.	g—175 r.p.m.
d—158 r.p.m.	h—185 r.p.m.

The speeds of the individual machines were uniform and showed no fluctuation. The wide difference in speed is due, undoubtedly, to the slippage of belts from one counter-shaft to the other.

Test 8—(American Machinery Co.)—Drawing Frames.

Speed taken from the driven shaft of the frame.

a—280 to 285 r.p.m.	c—280 to 284 r.p.m.
b—278 to 280 r.p.m.	d—284 to 288 r.p.m.

Test 9—(Saco-Pettee)—Slubbers.

Speeds were taken from the main driven shaft on the machine.

a—265 to 254 r.p.m.
b—272 to 274 r.p.m.

The mean average speed of the above is 264 r.p.m. The driven pulley should operate at 300 r.p.m. On this basis these machines are operating on an average of 36 r.p.m. under speed or 12 percent slow.

Test 10—(Saco-Pettee)—Intermediate Speeder.

a—358 to 364 r.p.m.	c—366 to 374 r.p.m.
b—362 to 368 r.p.m.	d—372 to 376 r.p.m.

This test shows the speed variation of the machines.

Test 11—(Saco-Pettee)—Finishing Speeders.

a—348 to 360 r.p.m.	d—348 to 360 r.p.m.
b—340 to 360 r.p.m.	e—354 to 360 r.p.m.
c—354 to 368 r.p.m.	f—352 to 360 r.p.m.

A considerable fluctuation is also apparent in the speed of the above machines, the average being 3.06 percent.

Test 12—(Saco-Pettee)—Spinning Frames.

a—890 to 900 r.p.m. } Spinning No. 18 Yarn.
b—815 r.p.m. }
c—730 to 740 r.p.m. } Spinning No. 14 Yarn.
d—720 to 730 r.p.m. }

The above indicates the greater loss in speed when spinning the heavier yarn.

Test 13—(Draper Automatic—32 In. Looms.)—Slashers.

The speeds were taken from the harness frames. In each case the endeavor was made to get the speed of looms which were driven from different counter-shafts.

a—156 Picks per Min.	d—158 Picks per Min.
b—158 Picks per Min.	e—156 Picks per Min.
c—160 Picks per Min.	f—154 Picks per Min.

The mean average number of picks per minute for the above looms is 157; according to the mill superintendent a 32-inch Draper automatic loom should operate at 170 picks per minute. This being the case, the above looms are operating at an average of 13 picks per minute under speed or an average of 7.67 percent slow. By operating these looms at 170 picks per minute 10 hours per day for 300 days and, as a basis by which to estimate, assuming that No. 13 warp is used, which requires 40 picks to make one inch of cloth, an increase in production could be obtained per year on each loom of 1 625 yards of cloth.

Test 14—(Draper Automatic 36 Inch Looms.)—Slashers.

Speeds were taken on the harness frames.

a—142 Picks per Min.	e—148 Picks per Min.
b—140 Picks per Min.	f—148 Picks per Min.
c—140 Picks per Min.	g—152 Picks per Min.
d—144 Picks per Min.	h—152 Picks per Min.

According to the information obtained from the mill superintendent, a 36 inch loom should operate at 160 picks per minute. The mean average speed of the above looms is 146 picks per minute. Thus the above looms are operating on an average of 14 picks per minute under speed or an average of 8.75 percent slow.

By operating these looms at 160 picks per minute and assuming that No. 13 warp is used, operating 10 hours per day for 300 days per year, would mean an increase in production on each loom per year of 1 075 yards of cloth.

The reason that the different machines were operating under speed, and also the cause for the variation in speed is due, in a great measure, to the slippage of belts, which takes place in transmitting power from one shaft to another. Proper power applications will reduce the belt slippage to a minimum and give a constant uniform speed.

The production of the above mill was increased 8.5 percent by operating the machinery at a maximum uniform speed. This was accomplished entirely through proper power applications to the machinery.

EFFECT OF INCREASED PRODUCTION

Taking as a working basis the data contained in Table IV, and using the figures for 1910, let us see what effect an 8.5 percent increased output will have upon the profits. The cost of the materials was \$280 218; an increased output of 8.5 percent would increase this figure to \$304 036. The cost of wages was \$100 346; with the increase in production this item of expense would increase approximately 6 percent. Wages would not increase in the same ratio as the production because only part of the labor works upon a piece work basis. Hence the labor cost would be \$106 366. Salaries and miscellaneous expenses would remain the same. The total cost to manufacture with the increased production would be as follows:—

Materials	\$304 036
Wages	106 366
Salaries	10 885
Miscellaneous expenses	27 213
Total cost of manufacture	\$448 700

The value of the product was \$574 616; with the increased output this figure would be \$623 458. The

gross profit would be the difference between the value of the products and the cost to manufacture, which is $174 758. To obtain this increased output would require an investment of approximately $60 000; adding this to the former capital would make the total capital $681 018. The percent profit, obtained by dividing the capital into the gross profit, thus amounts to 25.6 percent. Since the gross profit was 9 percent in 1910, it is seen that an 8.5 percent increased output would have resulted in an increase of 212 percent on the gross profit.

TABLE VII—POWER REQUIRED TO DRIVE COTTON TEXTILE MACHINERY

Machine.	Horse-power.	Machine.	Horse-power.	Machine.	
Creighton Bale Breaker	2.0	Three beater intermediate	8.0	[illegible]	[illegible]
Opener with feeder	2.5	One beater finisher	[illegible]	[illegible]	[illegible]
Automatic feeder	1.3	Two beater finisher	6.0	[illegible]	[illegible]
One beater breaker	5.5	Three beater finisher	[illegible]	[illegible]	[illegible]
One beater breaker for [illegible] mill	9.0	Cylinder opener	[illegible]	[illegible]	[illegible]
One beater breaker with exhaust fan and chute	7.5	One beater opener, vertical	4.0	[illegible]	[illegible]
Two beater breaker	7.5	Two beater opener, vertical	8.0	[illegible]	[illegible]
Three beater breakers	9.0	Exhaust opener	12.0	[illegible]	[illegible]
One beater intermediate	4.5	One beater opener without feeder	5.0	[illegible]	[illegible]
Two beater intermediate	6.0	Two beater opener without feeder	[illegible]	[illegible]	[illegible]
		[illegible] opener	[illegible]	[illegible]	[illegible]
		Top flat card	0.75	[illegible]	[illegible]

RING SPINNING FRAMES

Spindle speed.	Spindles per Horse-Power 7-10 Yarn	12-15 Yarn	20-30 Yarn	30-40 Yarn	40-50 Yarn
5000 r.p.m.	140	150	170	...	...
5500 r.p.m.	125	140	150	...	...
6000 r.p.m.	110	125	140	...	...
6500 r.p.m.	100	110	12[illegible]	...	...
7000 r.p.m.	90	100	110	...	...
7500 r.p.m.	80	90	100	..	...
8000 r.p.m.	70	80	90	..	...
8500 r.p.m.	63	70	80	[illegible]	100
9000 r.p.m.	54	63	70	...	[illegible]
9500 r.p.m.	49	54	60	...	...
10000 r.p.m.	...	...	..	[illegible]	65

MULE SPINNING

High speed, course numbers	120 spindles per hp
High speed, fine numbers	[illegible] spindles per hp
Moderate speed	160 spindles per hp
Spoolers, average	[illegible] spindles per hp
Spoolers, heavy	100 to [illegible] spindles per hp
Twisters, heavy counts	[illegible] to [illegible] spindles per hp
Twisters, fine counts	35 to 50 spindles per hp
Bobbin winders, horizontal	30 spindles per hp
Bobbin winders, vertical	[illegible] spindles per hp
Cone winders	25 spindles per hp
Warpers	0.25 hp
Scraper, 29 in. duck	3.0 hp
Scraper, 44 in. duck	3.3 hp

Scraper, [illegible]	[illegible]
[illegible]	[illegible]
Looms, [illegible]	[illegible]
Looms, 40 to [illegible]	[illegible]
Looms, [illegible]	[illegible]
Looms, [illegible]	[illegible]

For magazine or shuttle changing looms, add 15 per cent to above figures.

Bag looms	[illegible]
Duck looms	[illegible] looms per hp
Duck looms, wide	3 or 4 looms to 1.5 hp
Slashers	[illegible]
[illegible]	[illegible] hp
Lap double, with carding frame and connections	25 hp
Filling winder (French type)	140 spindles per hp
Filling winder ([illegible] type)	[illegible] spindles per hp
Filling winder (Wheton type)	300 spindles per hp
Quick traverse winder	[illegible]
[illegible] press	[illegible]
[illegible]	[illegible]
[illegible] machine	[illegible]
Double banding machine (6 heads)	½ hp
[illegible] machine	[illegible] hp
Yarn reel (single ordinary)	16 spindles per hp
Hank winder	5 reels per hp
Presses (125 ton)	2 hp
Presses [illegible]	[illegible]
Presses [illegible]	[illegible]
Measuring and [illegible]	[illegible]
Folding machines	[illegible]
Shearing machines	[illegible]
Brushing machines	[illegible]
Sewing machines	[illegible]
Thread extractor	[illegible]

HOW TO INCREASE PRODUCTION

The question is how to increase production. The mill in which the preceding tests were made succeeded increasing their output by driving the machinery with motors. In most instances individual motors were direct-connected to the machines. Some of the departments, however, were arranged into small groups and each group driven by a motor.

TABLE VIII—POWER USED IN COTTON TEXTILE ESTABLISHMENTS

Year	1870	1880	1890	1900	1910	1920 Estimated
Total horse-power	146 040	275 504	464 881	795 834	1 296 517	1 823 760
Percentage	100	100	100	100	100	100
Steam engines	55 967	110 750	265 509	514 176	869 838	890 000
Percentage	39	46	57	64.6	67	48.8
Water wheels	90 073	148 750	198 982	255 875	302 288	310 000
Percentage	61	54	42.8	32.3	23.4	17
Purchased Power electric	....	....	....	1922	108 512	606 760
Percentage	....	....	....	0.2	8.4	33.2
All other power	....	....	390	23 861	15 879	17 000
Percentage	....	....	0.2	2.9	1.2	1

NOTE —Percentages given represent the percent. of the total power used

The greater number of new mills built in the past few years and the additions to old mills are now driven by motors. Where attention was given to proper applications, these mills obtained a greater production than they could get with mechanical drive. Motors alone installed in a mill will not increase production; a most careful study must be given each application in order to secure the desired results.

HORSE-POWER REQUIRED TO DRIVE COTTON TEXTILE MACHINERY

The data in Table VII gives the horse-power required to drive textile machinery, as obtained by tests made in electrically-driven cotton mills. This data checks very closely with information furnished by the manufacturers of the machinery and data received from some of the best cotton mill engineers. The data quoted is for normal operation. If the speed of the machinery should be increased the power would be largely increased; a reduction in speed would of course require less power. The figures represent the net horse-power required at the driven shaft of the machine; to these should be added 20 percent to cover the friction loss between the machine and the driven head. The data applies to average conditions in a mill turning out an average class of goods; it will not hold good for those mills in which the product varies from the usual run of cotton goods.

THE SOURCE OF POWER

Whether to produce power from an isolated power plant or purchase electricity from a power company, is a question now before many cotton manufacturers. The textile industry is growing so fast that a system of power should be installed that will allow

FIG. 3—WHITIN SPINNING AND TWISTING MACHINES OPERATED BY 20 HORSE-POWER, 1 120 R.P.M. INDUCTION MOTORS, ARRANGED FOR FOUR-FRAME DRIVE

for future growth. Purchased power offers this advantage, as extensions and additions can be made at a minimum expense.

To assist in reaching a decision regarding the power to use, it will be well to consider the trend of times. Table VIII shows the total and also the different kinds of power used in cotton textile establishments since 1870. The last column giving a prediction for 1920, is based upon the power that will be used if the production reaches the amount the writer pre-

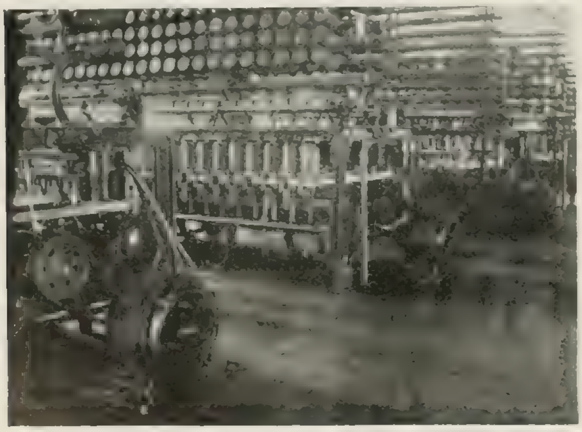


FIG. 4—COTTON TWISTING FRAMES FOR THE MANUFACTURE OF ARMY AND NAVY DUCK

Chain driven by five horse-power, 1 700 r.p.m. textile type induction motors.

dicts in the early part of this paper for the year 1920. A better idea of the trend of times and the tendency towards purchased power can be had by referring to Figs. 5 and 6, which illustrate graphically the different kinds of power used since 1870. These curves tell a story in themselves—for instance, in 1870 of all the power used, 61 percent was water power and 39 percent steam. As a usual thing where water power is available the transportation facilities are poor. The curves show that as the steam engine was improved

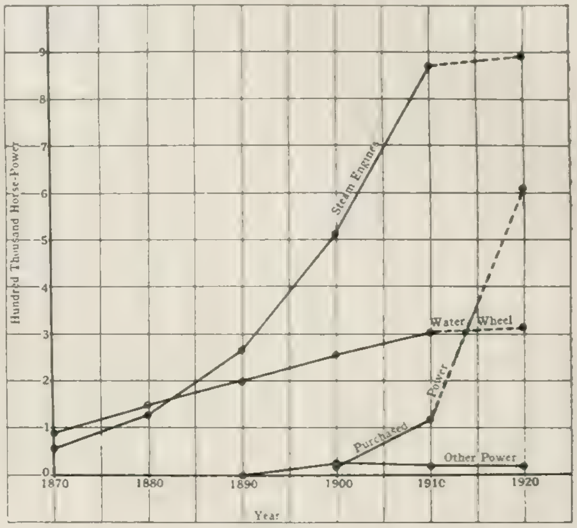


FIG. 5—CURVES SHOWING COMPARATIVE DEVELOPMENTS OF POWER SOURCES OVER 50 YEARS AND THE TENDENCY DURING THE PRESENT DECADE

and better transportation afforded more steam power was used. Purchased power did not come into use to an appreciable extent until 1900. Ten years afterwards it had reached 8 percent of the total power. The writer predicts that, as shown, by 1920, 38 percent of the total amount of power will be purchased.

At first glance this estimate may appear high, but if this industry grows in this decade at the same aver-

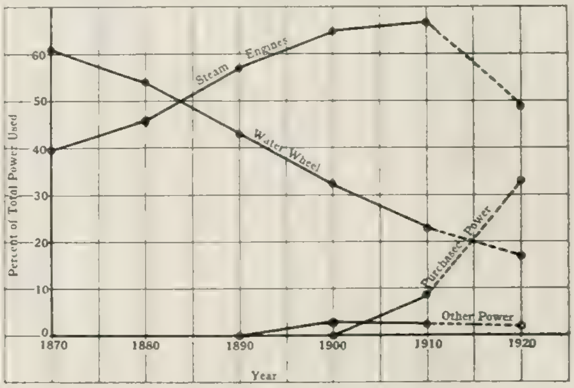


FIG. 6—RELATIVE AMOUNTS OF POWER PRODUCED FROM VARIOUS SOURCES

age increase as during the past fifty years, by 1920 there will be an increase of 537 000 horse-power, of which, it is safe to say, the greater part will be electric. Furthermore, with the rates now quoted by most power companies, the greater part of it will be purchased power.

Protection of Outdoor Transformer Substations From Lightning

Q. A. BRACKETT

THIS PAPER will not attempt to cover the large, high voltage su [illegible] ers are used, as that branch of the subject is so large as to deserve separate treatment. Also, the use of electrolytic arresters presumes that daily inspection will be made so that the arresters may be charged. Instead those types of lightning arresters are described which are suitable for the protection of out-door transformer installations where inspection will be at the best infrequent.

DURING the last few years the growth of outdoor transformer substations has been most rapid and the voltages employed have steadily risen. Located as they are at a distance from the main stations and usually in quite open and exposed positions, they must bear the full brunt of all lightning disturbances, and if damage is to be avoided and continuity of service maintained, the transformers must be very well insulated and well protected. In spite of this, many installations are either entirely unprotected and dependent on the insulation strength of the transformer and the aid of the distant power house arresters, or simple horn gaps with or without resistance are relied upon as the sole protection. The reason for this has probably been the lack of adequate lightning arresters of low cost for outdoor service. This difficulty has now been largely overcome by the production of various new arresters and the modification of certain existing designs.

FIG. 1—LOW-EQUIVALENT TYPE WESTINGHOUSE LIGHTNING ARRESTER FOR OUTDOOR MOUNTING

One of the oldest and most popular types of arresters that do not require attention, and therefore are suitable for use in an unattended substation, is the "Low-equivalent" arrester. This consists of a number of spark gaps in series with a low resistance all mounted on a marble panel, part of the gaps being also shunted by a resistance. In practice the gaps usually occur between knurled cylinders of non-arcing metal, while the resistances consist of rods of carborundum or other similar materials. The unshunted or series gaps determine the breakdown or discharge voltage and light discharges pass over them and through the shunt and series resistances to ground. If the discharge is so heavy that the two resistances in series would so impede it as to cause a high voltage to exist on the line, the shunted gaps will also break down and thus short-circuit the shunt resistance and afford a much freer path for the discharge.

After the discharge has passed and the voltage falls back to the normal potential of the line, the series resistance will so limit the current that it cannot maintain an arc across the shunted gaps because of the non-arcing quality of the metal and the current will be drawn out into the shunt resistance. This added resistance will still further reduce the current to a value where the series gaps can put out the arc. One of the great virtues of this type of arrester is the tendency of the gaps of non-arcing metal to put out the arc at the end of the first half cycle when the current is passing through zero. This means that there is little time for burning the gaps and little disturbance to the system.

While this general type of arrester has been in successful use for many years, it has always been considered an indoor arrester. Since, however, the adoption of the rod resistors instead of the rather cumbersome non-inductive wire-wound resistors formerly used, the size has been materially reduced, and advantage has been taken of this fact to mount these arresters in weatherproof cases for outdoor service, up to

FIG. 2—AN ARRESTER OF THE SAME TYPE AS THAT SHOWN IN FIG. 1, BUT WITHOUT SERIES RESISTANCE

27 000 volts. Fig. 1 shows one of these arresters for outdoor mounting on 10 000 to 14 500 volt lines. One of these is used between each line and ground.

In Fig. 2 another arrester of this type is shown, which differs from the preceding in that it has no series resistance. This gives greater freedom of discharge

but incurs greater risk that the discharge current may in some cases be too high to be ruptured by the non-arcing qualities of the gaps alone. For this reason its application is limited to lines fed by stations of capacities not over about 2 000 k.v.a. This style of arrester is made in two sizes, one for 1 200 to 3 500 volts and one for 3 600 to 7 000 volts, and for either indoor or outdoor mounting.

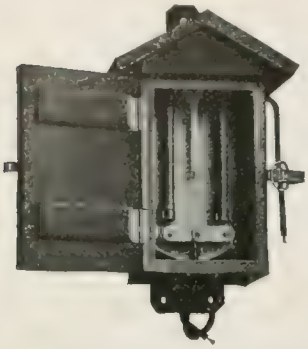


FIG. 3—OUTDOOR ARRESTER OF THE LOW-EQUIVALENT TYPE FOR 2 200 VOLT LOCAL DISTRIBUTION

For local distribution at 2 200 volts there is outdoor protection available in the arrester shown in its two-pole form in Fig. 3. This arrester is a simplified low equivalent type using the same non-arcing metal gaps and a series resistance for each phase leg. In the arrester shown there is one set of six gaps, the middle point of which is grounded. Between each line and each end gap is connected a 100 ohm resistance rod, thus inserting 100 ohms resistance and three gaps in series to ground from each line. No shunt resistance is used. The series resistance renders this arrester suitable for use on circuits of any capacity, while the non-arcing character of the gaps usually quenches the discharge arc at the end of the first half cycle of the generator current.

For the outdoor protection of 6 600 volt transformers an entirely new arrester is now available which does not require a wooden box for protection. This arrester shown in Fig. 4 is single pole and consists of nine non-arcing metal gaps in series with a resistance rod. These gaps are formed between punched metal cups strung upon a central insulated rod. The upper end of this rod is cemented into a porcelain insulator whose cap is provided with a cast eye by which the arrester may be suspended from the cross arm of the pole or from the line wire. The metal cups are accurately spaced apart by specially moulded porcelain washers. Below the gaps the resistance rod is enclosed in a weatherproof bakelite micarta tube. The only protection required for outdoor mounting is the conical metal hood that shields the gaps.

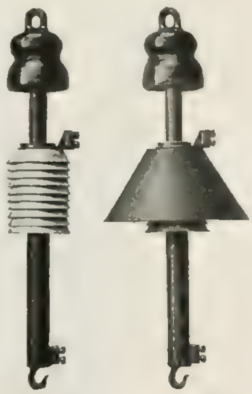


FIG. 4—6 600 VOLT ARRESTER FOR OUTDOOR SERVICE, WITH AND WITHOUT RAIN SHIELD

One important feature of the design of this arrester is the metal rod through the center. Not only does this serve as a backbone and to tie the parts of the arrester together, but since it is at ground potential it greatly increases the charging current across the upper gaps, which are really small condensers. If these gaps were only in effect a number of condensers in series, the voltage would divide up evenly among them, since the charging current would be the same in all cases. However, besides the series capacity effect each metal cup has a shunt capacity to ground, and this is greatly increased by the proximity of the center rod at ground potential. This shunt capacity charging current is added to the series capacity current and it is evident therefore that the upper gaps carry not only the series capacity current but the shunt capacity current of all the lower gaps as well. As the voltage across any gap is proportional to the product of the current times the capacity, the voltage across the upper gaps is much higher than that across the lower gaps. Accordingly it requires only a slight rise of potential to break down the upper gaps. This transfers the voltage strain to the lower gaps, which in turn break down in the same way. It is thus possible to use a much larger number of gaps in series for a given breakdown voltage than would be possible if the central rod at ground potential were not used to render the upper gaps more sensitive to rises of potential. This results in greater arc-rupturing power for the arrester, since after it breaks down the discharge current so far exceeds the shunt capacity current that the latter becomes negligible and the voltage between the gaps becomes practically uniform.

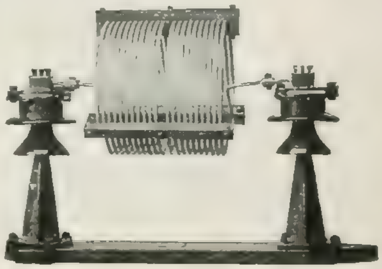


FIG. 5—CHOKE COIL WITH OUTDOOR MOUNTING FOR USE IN CONNECTION WITH LIGHTNING ARRESTERS OF THE OUTDOOR TYPE

This arrester, though designed especially for use on 6 600 volt lines, may be used two in series on 11 000 or 13 200 volt lines, by placing an extra insulator between the extra arrester and the point of mechanical support. Its simple construction, adaptability for either 6 600 or 13 000 volts service, and its availability for either indoor or outdoor service, should make this arrester very useful hereafter for the protection of the large number of 6 600, 11 000 and 13 000 volt outdoor transformers now coming into use.

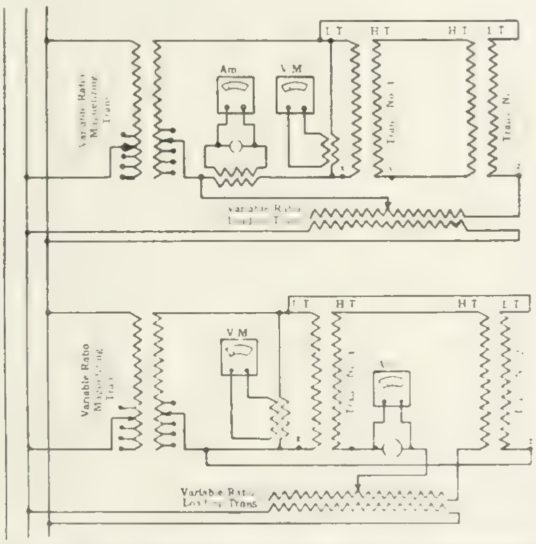
A choke coil is shown in Fig. 5 which is suitable for either indoor or outdoor service up to 27 500 volts. A unique feature is the design of the insulator supports which are so arranged that either end may be attached to either the coil or base, so that the coil may be supported either from above or below. The choking power of this design is about ten times that of the ordinary hour glass coil and, owing to the mechanical construction, it is impossible for the turns to be pulled together due to sagging or distortion caused by the magnetic forces during short-circuits.

Shop Testing of Electrical Apparatus—XVIII

SINGLE-PHASE TRANSFORMERS (Cont.)

TEMPERATURE RUN

THE temperature run is made to determine the temperature rise under given load conditions and to demonstrate the quality of the material used and the workmanship, in so far as is possible in a shop test. Transformers may be loaded directly on resistance racks or other means of dissipating power; or two or more of them in combination may be loaded artificially by the opposition or loading back method which consists in connecting the transformers so that while they are subjected to normal rated voltage and current, the only power to be supplied from an external source is the power necessary to supply the losses in the transformers. The scheme of connection ordinarily used in making this test is shown in Figs. 17 and 18. As regards the voltage due to the magnetizing transformer, the two transformers under test are

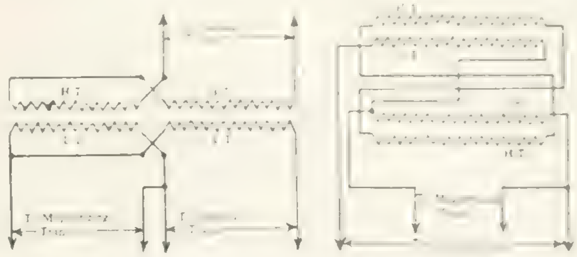


FIGS. 17 AND 18—LOADING BACK METHOD OF CONNECTION FOR TESTING TWO SINGLE-PHASE TRANSFORMERS

The difference between the connections of the two figures is that in one case the load current is supplied to the low tension windings and in the other to the high tension, covering high voltage and low voltage transformers respectively.

in parallel. The magnetizing transformer, therefore, supplies the combined core loss and volt-amperes excitation of the two transformers on test. With regard to the loading transformer, the two transformers being tested are in series. The voltage required to circulate full-load current in the windings will be equal to the sum of the impedance voltages of the transformers under test. The magnetizing voltage and the current supplying the copper losses may be supplied from the same phase of a three-phase supply or may be supplied from different phases or from different generators. In all cases the *load current* as well as the *magnetizing voltage* should be of normal rated frequency for the transformer being tested.

The relative phase relation of the load current and the magnetizing current tends to boost the load current. Of the six different combinations possible when loading from a three-phase supply, the relative phase relation of the magnetizing current and the load current should be such that the magnetizing current



FIGS. 19 AND 20—DIAGRAMS SHOWING METHODS OF CONNECTING INDIVIDUAL TRANSFORMERS FOR LOADING BACK

tends to give the smallest possible positive boost to the load current, since this condition gives nearest normal current in all windings of both transformers. In all cases, however, the load current should be adjusted until the ammeter indicates normal current; then the transformers are fully loaded and magnetized.

The method of loading transformers just described is applicable only when there are two or more similar transformers to be tested. When it is necessary to test a single transformer, several methods are available, the most common of which are shown in Figs. 19, 20 and 21. The method shown in Fig. 19 is applicable to any single-phase transformer when the high tension winding and the low tension winding can be divided into two equal parts. The disadvantage of this method is that two separate loading transformers are required to circulate the copper loss current in the windings. The scheme of connections shown in Fig. 20 is applicable to core-type transformers with non-interlaced windings only, on account of the fact that a core-type transformer, when connected as shown, will have sufficient magnetic leakage to allow the current to circulate in the windings.

The alternate open-circuit and short-circuit method of loading a transformer, Fig. 21, is effected by first exciting the transformer to be tested so as to obtain a

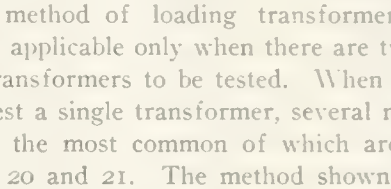


FIG. 21—CONNECTIONS FOR LOADING A TRANSFORMER BY THE ALTERNATE OPEN-CIRCUIT AND SHORT-CIRCUIT METHOD

core loss equal in value to the total losses of the transformer, and running it on open-circuit with this excitation for a fraction of a period t previously decided upon, equal to the ratio of the normal iron loss to the total loss. The transformer is next run on short-cir-

cuit with a current in the windings of such value as to give a short-circuit loss equal to the total loss for the remainder of the period *t*, which is a fraction of the total period equal to the ratio of the normal copper loss to the total loss. The cycle is repeated until the steady conditions are reached. With a length of period not too great, this method will give results closely approximating those obtained by the opposition method.

Temperature tests on transformers are generally run at normal rated load until steady temperature conditions have been attained. In order to shorten the time required for the transformers to reach normal operating temperature, an overload (usually 125 percent current and 120 percent voltage on 60 cycle transformers, or 125 percent current and 110 percent voltage on 25 cycle transformers) may be applied at the beginning of the run for such a time as will bring the transformers to approximately the final steady temperature. It has been found by experiment that approximately six hours with the overloads mentioned in the preceding sentence will bring a large power transformer to approximately the steady temperature, with shorter time for the smaller sizes. At the end of this time the voltage and current are reduced to normal and the run continued until the normal operating temperature is attained. This will usually take between 14 and 20 hours on large power transformers and six to eight hours for smaller distributing transformers. If overload runs are to be made, they should immediately follow the normal full load run.

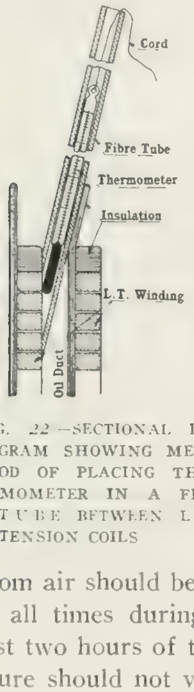


FIG. 22—SECTIONAL DIAGRAM SHOWING METHOD OF PLACING THERMOMETER IN A FIBRE TUBE BETWEEN LOW TENSION COILS

The temperature of the room air should be kept as nearly uniform as possible at all times during a temperature run. During the last two hours of the temperature run the air temperature should not vary over 1.5 degrees, owing to the fact that the change in temperature of the transformer due to the change in temperature of the air lags an amount which may introduce an error into the determination of the temperature rise. The temperature used as a base for computing the rise should be the average air temperature during the last two hours of the run.

Temperature runs on single-phase power transformers are generally made by the opposition method two at a time. At times, however, three single-phase units are tested at once by magnetizing closed delta from a three-phase supply and loading open delta from a single-phase. Since the procedure for this method is similar to that for a test on a three-phase unit it will not be described at present but will be dealt with under three-phase tests. Before starting a test the transformer tanks should be separated from each other and from any walls by a distance at least equal to the width of one of the tanks in order that there be ample ventilation. If the transformers are of the shell type construction a fibre tube of slightly larger internal diameter than a thermometer should be placed firmly between two low-tension coils, as shown in Fig. 22. No tubes can be placed in core type transformers, and the temperature of the adjacent oil or that given by thermometers placed against the surface of the high tension coils is taken as that of the windings.

Since the temperature rise of a transformer is based on the cold resistance, the greatest care should be taken to get this resistance accurately and to get the correct temperature of the windings at the time of taking the resistance. The resistance measuring leads should be connected directly across the terminals of the transformer at such points as may be easily duplicated for the hot resistance, and the resistance of all separate coils of both high tension and low tension sides measured. The thermometers used to measure the temperature of the transformers should be placed against the low tension coils and should remain there a sufficient time to be sure that the correct temperature is obtained.

The thermometer for observing the coil temperature should be tied to a cord and lowered into each thermometer tube in such a manner that it may be quickly drawn out when taking readings. The use of these tubes insures the return of the thermometers to the same places in the transformer after each reading. In order that the temperature of the oil in each transformer may be determined, a thermometer should be hung in each transformer with its bulb about two inches under the oil. A thermometer for indicating the temperature of the surrounding air should be hung about five feet above the floor and at such a distance, usually about six feet from the transformer, that it will not be affected by radiation. A thermometer used to indicate the air temperature of a very small transformer should be hung about half the height of the tank from the floor, as the air near the floor may be cooler than that higher up in the room. After having placed all thermometers and checked the voltage and current capacities of the magnetizing and loading transformers, the switch connecting the loading transformer to the power circuit should be closed, applying a very low voltage to the load circuit of the two transformers. The switch short-circuiting the ammeter should then be opened and the value of the current observed. The current should then be gradually increased to normal. The ammeter should always be short-circuited when making adjustments of current or voltage. When changing taps on the variable ratio magnetizing and loading transformers, always open the oil switch connecting those transformers to the power circuit.

The load current having been adjusted to its correct value, the oil-switch connecting the magnetizing

transformer to the power circuit should be closed, and the voltage on the transformer raised to normal. After the magnetizing voltage has been adjusted to its normal value, the oil-switch connecting the magnetizing transformer to the power circuit should be opened and closed, the load ammeter being observed when the switch is open and when it is closed. When the switch is closed the ammeter should show a slightly increased deflection or, if the magnetizing current is a very small percentage of the load current, the needle of the ammeter may swing slightly in a positive direction and finally settle to its original position, showing no readable increase in the current. When testing very large transformers full voltage should never be applied instantly. A reduced voltage, usually about 60 percent of the normal, should be applied first, and afterward gradually increased to normal. This precaution is taken to prevent a surge of exciting current which may occur when normal voltage is applied to any large transformer, and especially those transformers designed for 25 cycle service. While this surge may not be detrimental to the transformer being tested, it will tend to wreck the transformer supplying the magnetizing current, and especially the induction regulator if one is used to regulate the voltage. Should the ammeter show a decreased deflection when the magnetizing voltage is applied, or should the needle swing in a negative direction, the oil switches for both the magnetizing and loading transformers should be opened, and the leads of the magnetizing circuit reversed. After the leads have been interchanged and the normal load again applied, the ammeter reading should be again observed and the effect of the magnetizing current on the load current noted. If the ammeter needle shows an excessive increase in deflection when the magnetizing current is superimposed upon the load current, the switches should be opened, and the leads changed so that the magnetizing voltage is taken from another phase supply, that connection being used which gives the smallest possible positive boost to the load current. The switches should then be closed and the current in the windings adjusted to 125 percent of the normal rated value. The magnetizing voltage should be adjusted to 120 percent of the normal rated voltage for 60 cycle and 110 percent for 25 cycle transformers. These overloads are continued until approximately load temperature is reached when the current and voltage should be reduced to normal, and the run continued until the transformers reach a steady temperature. From the time the current and voltage are reduced to normal until the temperature has become constant the readings of all thermometers and meters should be observed every half hour and recorded on the proper forms.

When the temperature of the transformers, as indicated by the thermometers in the oil and on the coils, has been constant for four consecutive half-hour readings, and the surrounding air has not varied over 1.5 degrees during the four readings, the transformers are disconnected and the hot resistance of the transformer measured. The connection of the resistance measuring leads to the transformer terminals must be at exactly the same point or place used when measuring the cold resistance and the operation carried out as rapidly as is consistent with accuracy. In order to decrease the time required, all possible preparation should be made before disconnecting the transformers from the source of power. The bridge should be set in a position convenient to both transformers and the ratio and resistance arms of the bridge set at their approximate readings.

In measuring rise of temperature in water-cooled transformers the temperature of the ingoing water is used as a basis for the calculations of temperature rise instead of the temperature of the surrounding air. In the beginning of the heat runs of water-cooled transformers, it is customary not to start the circulation of water until the transformer has reached approximately its normal operating temperature. Similarly, in testing air blast transformers or forced-cooled transformers, the artificial cooling is not started until the transformer has reached approximately its normal operating temperature.

Assuming that the full load run is to be followed by some definite overload run which will not bring the transformers to a constant temperature, it is imperative that the run be started at the full-load operating temperature. If the temperature of the transformers has fallen appreciably during the time required to measure hot resistances and reconnect them, the run should be continued under full-load current and normal voltage until the temperature rise has again reached the same value as at the end of the full-load run. The specified overload should then be applied and readings taken of all thermometers and meters every half hour during the run. If a specified overload is to run until steady temperature conditions have been attained, the precautions given in the preceding paragraph need not be observed, but the overload may be applied immediately after measuring the hot resistance at the end of the preceding run. When a load run is specified for a stated period which will not bring the transformer to its maximum temperature, for instance, 100 percent load for eight hours, the cold temperature of the coils and the oil should be the same before beginning the run.

INSULATION TESTS

Electrically considered, the weakest point of a transformer is its insulation. It is essential, therefore, that any possible defects in the insulation, due to poor material or damage received during the process of manufacture, be detected and eliminated before placing the transformer in service. Insulation tests are made on completed transformers for determining the effectiveness of the insulation. This can be determined by actual test only. However, a careful mechanical inspection is often of value in eliminating condi-

tions that might cause a break-down unless corrected before making the electrical tests. This inspection should cover the following points or others of like nature:—

1—The condition of the terminal boards as to dirt, or other foreign matter, and cracks in porcelain bushings.

2—The clearance of leads from each other, and from any metal that may be considered as a ground.

3—The condition of such portions of the insulation as are exposed.

The insulation of a transformer is usually subjected to the following tests:—

1—Insulation resistance measurements.
  a—High tension to low tension.
  b—High tension to core.
  c—Low tension to core.
2—Disruptive tests.
  a—High tension to low tension and core.
  b—Low tension to core.
3—Overpotential tests.

INSULATION RESISTANCE

A high insulation resistance is not an absolute indication of the effectiveness of the insulation, yet in most cases when the insulation resistance is satisfactory no trouble will be experienced when the disrup-

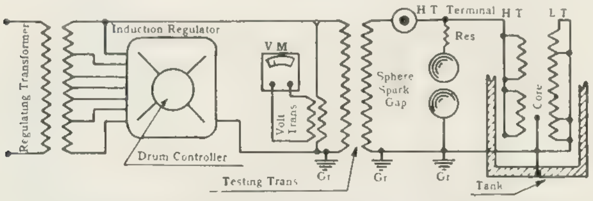


FIG. 23—DIAGRAM OF A DISRUPTION TEST SHOWING METHOD OF CONNECTING SPHERE-GAP

tive tests are applied This test is usually required on transformers in which the major portion of the insulation is of a fibrous nature and such transformers should never receive the disruptive tests unless the insulation resistance is satisfactory, as low insulation resistance is usually an indication of the presence of a dangerous amount of moisture or other foreign matter. A resistance of 2.5 megohms at approximately 70 degrees C. for every thousand volts test voltage is usually required for very high voltage transformers. For low voltage transformers 1.75 megohms per thousand volts test voltage may be considered satisfactory. The insulation resistance is usually measured by means of a megger, or by the series voltmeter method.*

DISRUPTIVE TESTS

Disruptive tests should, in general, be made after the transformer is completely assembled, and not on the individual parts. The transformer should be in good condition, and the clearance for all leads from each other and from the tank should be the same as for normal operation. Unless otherwise specified, these tests should be made with the transformer at approximately normal operating temperature. Therefore, in the majority of cases it is most convenient and most economical to make these tests immediately after the temperature runs. If no temperature runs are made it should be short-circuited and run for sufficient time to heat it to approximately normal operating temperature. To accomplish this, one winding, usually the low tension, should be short-circuited, and sufficient voltage impressed in the other winding to cause some definite percent (usually 125 percent) of full-load current to flow in the windings. This short-circuit run should be continued for such a period as will bring the transformer to approximately normal operating temperature. The test voltage which should be applied to determine the effectiveness of the insulation is dependent upon the type and size of the transformer and its normal operating voltage; upon the nature of the service in which it is to be used and the severity of the mechanical and electrical stresses to which it is liable to be subjected.

When disruptive tests are made with 60 000 volts or more, a spark-gap should always be used. Without a spark-gap there is no measure of the actual testing voltage, because of the voltage rises in the testing circuit by the electrostatic capacity of the transformer under test, by reason of which the ratio of the testing transformer cannot be taken as equal to the ratio of the number of turns. When a needle gap is used, the setting for a given voltage may be determined from the standard A. I. E. E. calibration curve* for this type of gap. This gap is seldom used for voltages above 100 000 because the formation of corona on the needle points renders it unreliable. After each discharge of a needle gap the the needles must be replaced, otherwise the calibration of the gap is changed.

When a sphere-gap** is used, the proper setting for a given voltage must be determined from a calibration curve furnished with the gap. The sphere-gap has the advantage that there are no spark-points to be renewed and that its calibration is practically constant, being almost totally unaffected by atmospheric conditions. The sphere-gap however, should not be used when the separation of the spheres is greater than their diameter since the formation of corona just preceding the breakdown renders it inconsistent.*** In all cases when a spark-gap is used, whether a needle or a sphere-gap, sufficient non-inductive resistance (usualy about one ohm per volt) should be inserted in series with the gap to limit the current at discharge to a small amount. The circuit-breaker in the low tension circuit of the testing outfit should be set to open when a discharge occurs across the gap or should a breakdown occur in the transformer. The spark-gap should be connected, as shown in Fig. 23, and the distance set according to the calibration curve. The circuit breaker in the low tension circuit should

*See Section II, in the JOURNAL for February, 1913, p. 146.

*Given in Fig. 6, p. 294, of the JOURNAL for March, 1913.

**See article on "The Sphere-gap" in the JOURNAL for May, 1913, p. 455. Also, curve in Fig. 6, p. 295, of the JOURNAL for March, 1913.

***See "The Dielectric Strength of Air." The Philosophical Magazine and Journal of Science, Volume II, Sixth series, p. 237.

be set to open at the first discharge across the gap. The voltage should then be raised gradually until a discharge takes place in the gap, when the voltmeter across the low tension circuit should be read. The regulator should then be turned to the lowest point, the oil-switch in the low tension circuit opened and the spark-gap adjusted for a voltage ten percent higher than the test voltage. The oil-circuit-breaker and oil-switch in the low tension circuit should then be closed in succession and the voltage raised to the value indicated by the voltmeter at the instant of the discharge in the gap previously. After this test has been applied for the specified period, usually one minute, it should be reduced gradually and continuously to the lowest value possible and the oil-switch in the low tension circuit opened. Care should be taken in all cases not to increase or decrease the test voltage in large steps.

All test voltages specified are root-mean-square values of a sine wave e.m.f. The length of time the test voltage should be applied depends upon the ratio of the test voltage to the normal voltage of the transformer under test. While the insulation of the transformer under test may stand the momentary application of a voltage three or four times normal, the con-

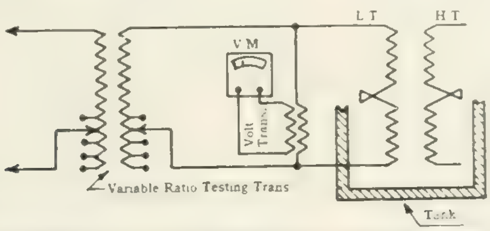


FIG. 24 DIAGRAM OF CONNECTIONS FOR OVER POTENTIAL TEST

tinued or repeated application of such a voltage would probably weaken the insulation permanently. When making disruptive tests the voltage should always be increased or decreased gradually and continuously. This may be done by any one of several methods, which, in order of preference, are as follows:—

1—By means of an adjustable field alternator and a fixed ratio high potential testing transformer.
2—By means of a regulating transformer with a floating induction regulator and a fixed ratio high potential testing transformer.
3—By means of a step-by-step potential regulator and a fixed ratio high potential testing transformer.

When making insulation tests between the high tension winding and the low-tension winding and core, the low tension winding should always be thoroughly grounded to the core. If this is not done, the low-tension will act as one plate of a condenser and an induced potential be set up which may strain the insulation much more than would the test voltage for which it is designed. For similar reasons, when testing the insulation of a transformer having a number of taps on the respective windings, all taps on each winding should be short-circuited and the terminals of the respective windings connected together outside the tank. If the test voltage is applied to only one terminal without short-circuiting the taps, the potential strain will vary throughout the winding, and at some places may be even greater than at the terminal where the voltage is applied. Under such conditions the voltmeter reading or the discharge across the spark-gap may not be a true indication of the maximum voltage to which the insulation is subjected.

[illegible]

While the insulation of a transformer may give no trouble at normal voltage, it may break down at an applied voltage in excess of normal, such as would be caused by a line surge. The ability of a transformer to withstand such a surge depends upon the insulation between turns and layers. To determine the effectiveness of this insulation the overpotential test is applied, usually after the disruptive tests, since it will then make apparent any damage which may have been done the insulation between times by the preceding tests.

This test is usually made with 200 to 400 percent of normal voltage; therefore, if normal frequency is used to make this test the exciting current will be excessive. In order to prevent this excessive current, the test should be made with increased frequency. If the frequency be increased in direct proportion to the voltage there will be no increase in the magnetic density and the exciting current will be approximately the same, but the kilovolt amperes required to make the test will increase in proportion to the voltage. Where this is of no importance it is customary to test 25 cycle transformers on 60 cycles and 60 cycle transformers on 125 or 133 cycles. Where testing is done on a large scale, it is customary to use 500 cycle current on low and medium voltages. If, however, the high tension voltage would exceed 40 000 volts, the test should be made with a lower frequency, to prevent an abnormal voltage rise that may result by reason of the high frequency and the electro-static capacity of the transformer being tested.

The transformer should then be connected for the over-potential test according to the diagram in Fig. 24. After all connections have been made, the oil-switch connecting the testing transformer to the supply circuit should be closed, applying a low voltage to the transformer under test. If there are no indications of trouble, the voltage should be gradually increased to the specified test value (usually 200 to 400 percent of normal voltage) and the test continued for the specified period (usually five minutes). The voltmeter should be observed at frequent intervals, as a sudden drop in the voltage is an indication of a short-circuit in the transformer under test. Should there be a short-circuit initially, difficulty will be experienced in adjusting the voltage of the testing circuit to the required value.

If the terminal voltage of the transformer to be tested would be higher than can be obtained from the testing transformer, a single transformer of suitable ratio should be used, rather than to step up the voltage successively through several transformers, as in the latter case there is a possibility of excessive voltage being produced through resonance.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1065—Water Purification By Ozone— Please refer us to recent works or articles on water purification by means of ozone. L. J. S. (Mass.)

Proceedings American Water Works Association, 1910, article by Walden & Powell; Popular Electricity, 1911, pp. 439 to 441, "Ozonized Water for St. Petersburg"; Electrical World, November, 1911, "Production and Uses of Ozone in Europe"; Engineering News, April 28, 1910, "The Production and Utilization of Ozone with Special Reference to Water Purification"; Engineering Record, July 20, 1912, "The Commercial Production of Ozone"; Scientific American Supplement, April 27, 1912, "Industrial Uses of Ozone"; London Electrician, Sept. 6, 1912, "Electric Sterilization of Water"; Scientific American, June 1, 1912, "Ozone Sterilization"; Metallurgical and Chemical Engineering, November, 1913, December, 1913, January, 1914, articles by A. Vosmaer; Commercial Engineering for Central Stations, McGraw-Hill Book Company, chapter on "Ozone", by Arthur Williams and Edmund F. Tweedy; "L'Ozone et ses Applications Industrielles, Propietes, Physiques, Physiologic, Production, Actions Chemique and Microbicide, Applications, Analyse," by R. de LaCoux, comprehensive work, 611 pages, second edition; London Engineer, December 1, 1911, "New Water Purification Works at St. Petersburg"; Transactions American Institute of Chemical Engineers, Vol. III, p. 188, Oscar Linda, "Manufacture and Industrial Applications of Ozone"; Electrical World, December 27, 1913, p. 1345, "Water Purification by Ozone in Large Office Buildings"; Electrical World, December 13, 1913, p. 1231, "Ozone Water Purifying Apparatus"; Electrical Review and Western Electrician, December 14, 1912, p. 1144, "New Electric Sterilizer". W. H. T.

1066—Potential Transformer Ratio— In testing turbo-alternators, the connections shown in Fig. 1066 (a) are used on the potential transformer circuits. The neutral of the generator is

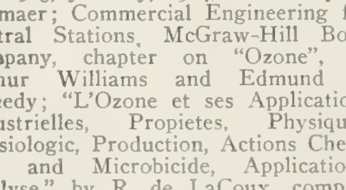


FIG. 1066 (a)

not earthed and the ratios of the transformers are as follows:—*A*, 5 to 1; *B*, 4.9 to 1; *C*, 4.95 to 1. It is desired to read the line voltage on leads *1*, *2* and *3* from the secondary windings. How is the ratio affected by errors in phase transformers? Would earthing the neutral give more accurate readings due to slightly different characteristics in the phase transformers? D. K. C. (England)

With three potential transformers having unequal ratios of turns connected in star as shown in Fig. 1066 (a), it is impracticable to determine the exact line voltage from readings of secondary volts on leads *1*, *2* and *3*. It is obvious that the secondary voltage between any two leads is the resultant of two voltages, having no definite phase relation. This is practically equivalent to two transformers with unequal ratios of transformation connected in series on both primary and secondary windings respectively. While each transformer has a definite ratio, there is no definite ratio of line to secondary voltage. Grounding the neutral of generator and transformers would have the effect of maintaining a 120 degree phase relation of the primary voltage. With this arrangement, ratios of transformation can be established for any two of the three transformers, and in this case, the ratio of transformation of transformers *A* and *B*, would be 4.96 to 1; that of transformers *B* and *C*, 4.93 to 1, and that of *A* and *C*, 4.98 to 1. Having the neutrals of generators and transformer grounded, a better plan would be to read the secondary volts, *1-N*, *2-N*, and *3-N*, and from the actual ratio of transformers *A*, *B* and *C*, determine the phase voltage of the generator. Knowing the phase relation of voltage to be 120 degrees, the line voltage would be equal to the phase voltage multiplied by the square root of three, providing the voltage per phase was equal. If, however, the phase voltages were unequal, the voltage of any two lines would have to be determined by trigonometrical solution from the voltage value of the respective phases. W. J. H.

1067—Three-Phase Wattmeter Connections— Two feeders have an integrating wattmeter on each and a totallizing curve drawing wattmeter on both. With the number and arrangement of current transformers as shown in Fig. 1067 (a), give a diagram of the connections, such that all three meters will work properly with either or both feeders loaded, with the busses either tied together or separate (at the same voltage), or with one of the busses dead, as in case of repairs, while the other operates. C. F. P. (Ontario)

The totalizing meter in question is assumed to have separate and independent meter elements acting collectively upon a single recording mechanism. In this case all three meters will operate correctly if connected as indicated, under all conditions stated. With proper design of coils in the totalizing meter, there will be no influence of one meter element upon the other. Relay type totalizing meters can now be obtained for totalizing any number of such circuits. Connections to current coils of meters only are shown, and it is assumed that leads from the potential transformers will be con-

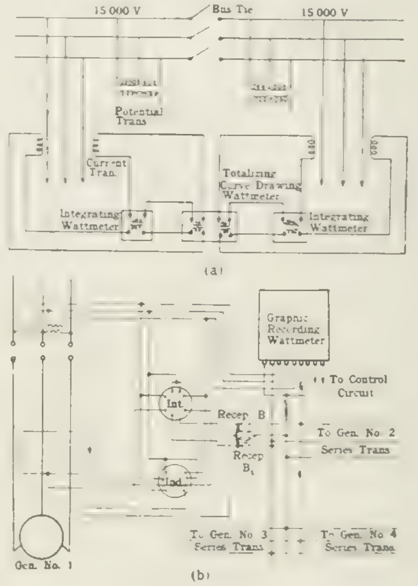


FIG. 1067 (a) and (b)

nected to the proper potential coils of the wattmeters to correspond with the current connections shown. With these connections the circuits are not necessarily operated in synchronism. If they are to be operated always in synchronism the series transformers may be paralleled, as shown in Fig. 1067 (b), using an ordinary polyphase graphic recording wattmeter with heavy series coils. The capacity of any graphic wattmeter may be doubled by reconnecting the series coils in parallel. The ratios of all series transformers must be the same. P. M.

1068—Electro-Plating Dynamos— I want to wind and connect up a four-pole electro-plating dynamo. The armature has 16 slots and the commutator has 16 segments. Please tell me how many slots there should be between the two sides of each coil. Also, how it should be connected to the commutator. A. T. B. (Ohio)

It is impossible to state just what type of winding would be most satisfactory without knowing the dimensions of the machine, its capacity, speed and voltage rating, etc. A multiple wound armature with one turn per coil would probably be satisfactory. Figs. 1034 (a) and (b) show two ways in which to wind and connect a multiple-wound

one turn per coil armature with 16 slots and 16 bars. Fig. 1034 (a) shows the armature wound with one slot chording. From bar one the conductor goes to the top of slot one, than to bottom of slot four and then to bar two, etc. Fig. 1034 (b) shows the same armature wound full pitch. The conductor runs from bar one to slot one, to slot five, to bar 16, etc. Under certain conditions, commutation may be aided by chording the winding. Referring to Fig. 1034 (a), it will be seen that when the con-

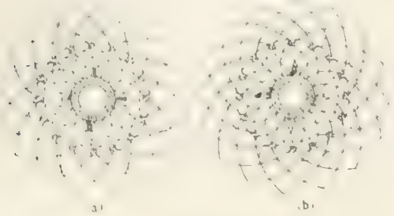


FIG. 1034 (a) and (b)

ductor in slot three is passing through the commutating zone, the other side of the coil (in slot 16), has already advanced into the magnetic field under pole *A*. If this has the proper strength, the reactance voltage due to the armature current will be partly neutralized and the commutation will be improved. If, however, the conductor is too far advanced under the pole, the advantage of the chording will be more than offset. In general, it is not desirable to have the conductor advanced beyond the pole tip. Whether a chorded or full-pitch winding is preferable, depends then on the tooth pitch and the width of the pole. With only 16 slots, unless the diameter of the armature is very small, the full-pitch winding would probably be most satisfactory. K. L. H.

1069—Lead Burning Outfits—Where can I get material, tools and machinery for lead burning? Can you give me a sketch of a small lead burning outfit and the necessary materials to make the same? R. D. J. (Idaho)

A lead burning machine consists of a hydrogen generator, an air tank and an air pump. The generator is made of lead or other acid-proof material and is divided into two compartments, the upper one being open at the top and the lower one air-tight. A lead pipe extending nearly to the bottom of the lower chamber connects these two chambers. A perforated shelf on which is placed commercial zinc is placed about two inches from the bottom of the lower chamber. Twenty to twenty-five pounds of zinc will last all day, about three ounces being required per cubic foot of gas. A mixture of five parts water to one part by valence of commercial sulphuric acid is poured into the upper chamber. This flows into the lower chamber, where it acts on the zinc. Hydrogen is generated and the pressure which is formed forces the liquid back into the upper chamber, the column of the liquid in the connection pipe giving the pressure in the gas chamber. By means of rubber tubes the hydrogen gas and compressed air are conducted to the blowpipe. J. S. K.

1070—Current to Anneal Hard Copper—Please state the amount of current necessary to anneal 2-0 and 4-0 hard drawn trolley wire. H. M. G. (Conn.)

If the wire is freely suspended in still air as a single loop No. 2-0 wire will anneal under a current of about 800 amperes; 4-0 will anneal under a current of about 1 000 amperes. If the wire is in a coil or protected in any way from free convection, less current will suffice; if subjected to air current of any appreciable velocity more heating current will be necessary. It is impossible to give the exact current requirements without knowledge of the conditions under which it is proposed to do the annealing.

1071—Protection of Rotary Converters—In a railway sub-station where the rotary converters have no overload protection on the alternating-current side, would it not be well to put in two circuit breakers similar to those used on the direct-current side on the feeders? When one of the machines bucks, it remains connected to the alternating-current line and throws fire until the operator pulls the alternating-current switches, and in some cases considerable damage results. C. W. (Ohio)

This answer must be a general one, dealing with the general practice of protecting 600 volt, three-phase converters. Standard practice is to have each converter operated from a separate bank of transformers, and for each bank to have its high side an automatic circuit breaker for the protection of both the transformer and the converter. On the direct-current side the practice is to have an automatic circuit breaker in the lead opposite the series field (in the positive lead, assuming the series field to be in the grounded negative lead). This circuit breaker protects against overload on the direct-current side to the trolley, but will not protect against a ground on the positive lead occurring between the converter and the circuit breaker. To protect against a ground of this nature or a ground on one of the alternating-current leads to the converter, the practice is to install a circuit breaker in the negative brushholder lead ahead of the series field, which is set at a higher value than the positive circuit breaker, in order that the positive circuit breaker (mounted on the switchboard and accessible to the station attendant) may take care of an overload on the converter to the trolley bus. This protects, therefore, against any grounding from the positive brush of the machine to the frame of the converter and against any damage due to ground on any alternating-current lead. To protect against damage caused by bucking, reliance must be had on circuit breakers on the alternating-current side of the machine. This can be accomplished by circuit breakers on the high-tension side of the transformer bank as stated above, or in the alternating-current leads to the converter. It should be noted that where no circuit breaker is supplied in the negative brushholder lead, every alternating-current lead to the converter should have an overload circuit breaker; that is, a three-phase converter should be protected on the alternating-current side by a three-pole circuit breaker. This is in order to afford the converter complete protection against bucking and against grounds. Where a circuit breaker is supplied in the negative brushholder lead, this will supply sufficient protection against ground, and in this case a two-pole circuit breaker with a three-phase converter will provide the additional protection to the converter to make protection complete. Nevertheless, it should be added that it is preferable to install a three-pole circuit breaker so as to open each alternating-current lead to the converter. Special protection against bucking is afforded by:—

1 [illegible] circuit breaker, the alternating-current cir- [illegible] interruption of the latter (as by the open- [illegible]

2 [illegible] ated from the alternating-current side and interlocking the direct-current circuit [illegible] when the alternating-current power to the converter fails, and when the alternating-current voltage is not held up through the converter from the direct-current bus. This scheme insures against return of full [illegible] rectly on the converter.

3 [illegible] anism, actuated from the alternating-current side; interlocking the direct-current with the alternating-current circuit breaker; and providing a reverse current relay on the direct-current side. This combination permits of a general application.

The application of these schemes to overcome bucking should not be made until the actual cause of the bucking has been determined, as so many conditions operate to produce bucking, some of which can be protected against in a simpler and less expensive way than others. O. W.

1072—Switchboard Connections—We are installing a new switchboard and new wiring in an old plant. The old 550 volt direct-current panels are equipped with one circuit breaker, two generator switches, field switch and equalizer switch. The new panels are equipped with one circuit breaker and one generator switch, as shown at Fig. 1072 (b). I propose to change the old and wire up the new panels as at (c), installing a field switch on each panel at the right of the generator switch and mounting an equalizer switch at each machine. By so doing I can save about 2 000 pounds of copper. What are the merits of (a) and (b) and objections to (c)? E. M. B. (Wash.)

In the scheme shown in Fig. 1072 (a), the circuit breaker should be actuated by the entire generator current and the opening of the circuit breaker should completely open the generator circuit. (See "National Electric Code", Section 1-D). With connections as shown by (a), the opening of the circuit breaker will permit the generator to feed into the bus-bars through the positive and equalizer leads. To remedy this defect the circuit breaker should be placed in the positive side, (that is, in the side opposite the series field). The field switch, if used at all, should have

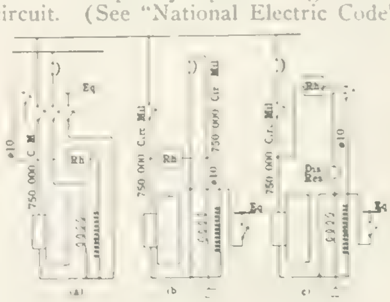


FIG. 1072 (a), (b) and (c)

field discharge contacts and resistance. Preferably the field switch should be omitted altogether, as with direct-current machines the field switch serves no necessary function. With changes made as recommended, standard generator connections for power and lighting switchboards will be obtained. With this type of board the positive and negative busses are mounted at the board. With the type of switchboards used in railway service it is the practice to have only positive bus at the board and the grounded negative and equalizer busses between the machines. The connections shown by (b) have the same defect as the connections shown by (a). The circuit breaker should be actuated by the entire generator current and the opening of the circuit breaker should completely open the generator circuit. In this case the defect can be remedied by connecting the equalizer lead directly to the grounded side of the series field. With this change the connections will be in accordance with the National Electrical Code rules, Section 1-D, for engine driven generators with one terminal grounded. With the circuit breaker on the switchboard, where it is convenient to the station operator, this requires running cable to the circuit breaker and back again to the series field of the generator. This may bring about a large cable expense and warrant (particularly with large machines and long runs of cable between generator and board) the installation of two circuit breakers; one at the board in the positive lead and one in the negative brushholder lead on a pedestal with the equalizer switch located at the machine. The circuit breaker at the switchboard is set for lower currents than the circuit breaker on the pedestal, so that for normal overloads only the switchboard circuit breaker would operate, permitting the pedestal circuit breaker to take care of the grounds or short-circuits on the machine not protected against by the switchboard circuit breaker. This arrangement is for convenience of operation, but means the added expense of another circuit breaker and the expense of a larger pedestal. This expense, however, is offset by the saving in the cable to the switchboard and by the greater convenience in operation. It should be understood that these remarks referring to (b) apply to engine-driven generators only. When the generator is electrically driven, protection against grounds on the machine is afforded by protective apparatus which should be provided in the circuit of the driving unit. In this case no circuit breaker is required in the grounded lead by the National Electric Code, and the connections shown by (c), therefore, are correct. It is preferable also to omit the field discharge switch and resistance. To sum up: Connections as shown by (a) (except that circuit breaker should be located in the positive side) are standard for light and power switchboards which require positive and negative busses on board. Connections as shown by (b) (except that equalizer circuit should be connected directly to the ungrounded side of the series field) are standard for small capacities of engine-driven generators with ground return (railway service). With large capacity engine-driven machines the connections shown at (c) are standard, except that another circuit breaker should be provided in the negative brushholder lead. The connections shown by (c) are also standard for electrically driven generators for railway service with protection provided in the driving side. O. W.

1073—Grounding Lightning Arresters—(a) In electric railway work is it desirable to bond lightning arrester ground rods to the rails? (b) If the ground rod is bonded to the rails, is there not danger of the ground rod being destroyed by electrolysis due to return current leaking into the wet earth pipes, etc., especially at points remote from the power station? (c) Without the ground rod bonded to the rail, is it possible that the rails may take on a charge from lightning, as do the feeders, and discharge upward through the car and to ground over the lightning arrester, and burn out the motors, controllers, etc., in so doing? (d) Telephone wires of a fifty-mile interurban despatching system terminate at one end in a piece of lead-covered overhead cable about 11 000 feet long. Insulating transformers are provided between the open lines and the cable. Should the cable sheath and messenger be grounded? C. L. G. (Texas)

(a) We recommend connecting lightning arrester ground wires both to the ground and to the rails. (b) It is true that there is danger that the ground rods will be injured by electrolysis, but if rugged grounds are used, this will not happen quickly, and, in any case, lightning arrester grounds should be inspected frequently. (c) While the danger from charges on the rails is not as great as that from charges on the overhead wires, there is always the danger from that source, if the rails are not thoroughly grounded. (d) Yes. Q. A. B.

1074—Shape of Pole Tips—We have a 225 horse-power, 220 volt, direct-current motor working on the hoist of a bridge. The armature fanned out on lowering and crushed one side of the pole tips back, as shown in Fig. 1074 (a). What effect will this have on the operation of the motor, if again put in service without rectifying the trouble with the pole tips? W. H. M. (Ohio)

The effect of having the pole tips of a motor crushed as indicated can most

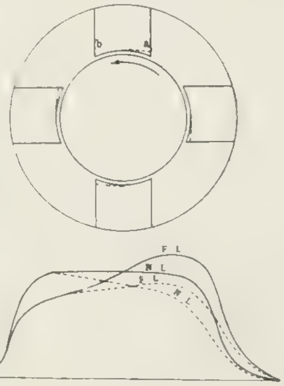


FIG. 1074 (a)

easily be seen by referring to the field form. Let the full lines represent the field forms with normal poles, and the dotted lines the field forms with pole tips crushed. When the motor is running in the direction indicated by the arrow the armature m.m.f. tends to magnetize the horn *a* of the pole and demagnetize the leading horn *b*. That is the flux will be crowded towards the trailing horn, and unless the motor is supplied with interpoles the full-load neutral will be shifted in the direction opposite the direction of rotation. When one side of the pole is crushed the no-load field form will be unsymmetrical. The magnetizing force of the armature under the trailing corner of the pole will tend to make the full-load field form more symmetrical, and unless the distortion of the pole is excessive, the motor will operate satisfactorily. When running in the opposite direction, however, the armature current will magnetize the leading pole corner where the flux density is highest. This would cause an appreciable distortion of the field form and bad commutation would probably be the result, especially if the motor is of the non-interpole type. The load speed will probably be higher, due to the fact that the leading pole horn will become saturated and the total flux per pole will be lessened K. L. H.

1075—Operation of Compound Motor—I have a 25 kw, 220 volt compound-wound generator which I want to run as a motor. Will I have to reverse the compound winding? L. H. W. (ILL.)

Referring to Fig. 1075 (a), assume that, when the machine is running as a motor, the direction of the shunt and series field currents are as indicated by the arrows. The counter e.m.f. of the

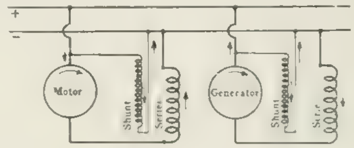


FIG. 1075 (a)

motor *e* is, of course, opposite to and slightly less than the impressed e.m.f. *E*, and the current is determined by the formula $\frac{E-e}{R} = I$, where *I* is the armature current and R the combined resistance of armature and series field. Supposing now that the motor speed is governed by some independent source (engine or motor) and the field strength or speed is increased sufficiently to raise the counter e.m.f. above the impressed e.m.f. or line voltage. The motor will then run as a generator and it will be noticed that while the shunt field current is in the same direction the series field current has been reversed and unless the connections are changed, the shunt and series field would be opposed. See also article on "Parallel Operation of Generators" in the JOURNAL for November, 1911, p. 974. K. L. H.

CORRECTIONS

In the JOURNAL for May, 1914, in line 23, first column, page 280, the word "impossible" should read "possible."

In the JOURNAL for June, 1914, the title to Fig. 3, page 321 should read "1 500 r.p.m." The title to Fig. 3, page 370, should read, "A curve of amperes taken with an ammeter of the type shown in Fig. 1." In a few copies of this issue, the sub-title to Fig. 5, page 344, was omitted. This should read, "The ordinates represent the ratio between the amounts of energy radiated by the two lamps at various wave lengths."

The Electric Journal

VOL. XI AUGUST, 1914 No. 8

The "Safety First" Movement

A great deal is being written, both in the technical and the lay press about the campaign for "Safety," and to the uninitiated it would appear as though an entirely new movement had been but recently launched looking to the safety, sanitation and welfare of workers generally throughout this country. Such, however, is not the case, for the present activity is simply the logical outcome of persistent and long continued effort on the part of individual employers of labor, labor representatives and welfare workers, with the result that the movement has finally gathered sufficient impetus to attract the attention of the public generally.

Unfortunately there is as yet no universally recognized central body to whom either those already participating or those desiring to participate can turn for authoritative information as to how best to proceed, what is necessary, what is practical and so on. In consequence, money, labor and time are being inefficiently expended by employers and others, groping more or less in the dark and along almost identical lines, all learning in the main the same lessons, but being unable to transmit to other than a few, the results of their individual experiences, simply because as stated, there is no recognized medium of intercommunication.

In Europe, twenty-two museums or societies are engaged in this work; and, while their efforts are largely along lines parallel to one another, there is some measure of excuse for it, owing to the great dissimilarity in language and customs. Yet, how much greater progress would already have been made, could these various societies have undertaken separate fields of work and each then placed the results of its labors regularly before the others for mutual use. In America, two societies have thus far come into existence as a direct consequence of the safety movement; namely, the American Museum of Safety and the National Council for Industrial Safety, both of whom are doing yeoman work; but as other societies to cover practically the same field are either already forming or being contemplated, there is danger that America, like Europe, will fail to concentrate her efforts, thereby similarly wasting her opportunities and with not even the semblance of an excuse.

The average person imagines the "Safety First" movement simply means the safe-guarding of moving machinery, dangerous passages, and the like. In this issue of the JOURNAL, the excellent article on the safety work of the Youngstown Sheet & Tube Company, by Mr. J. L. Woltz, shows the safe-guarding of machinery to be but a single feature of a movement which embraces several sides. As bearing out this statement, Mr. Howard Elliott, chairman of the New York, New Haven & Hartford Railroad, remarks in his book, "The Truth About the Railroads," that but one twelfth or 8-1/3 percent of all accidents on American railroads could be prevented by having a full equipment of mechanical appliances. Similarly, the United Gas Improvement Company in an analysis of 2 000 accidents shows that but one half of one percent were due to defects or lack of guards on machinery. A study of accidents in the works of the Westinghouse Electric & Mfg. Company for 1913, shows that only three-tenths of one percent were due to lack of safe-guards, while twenty-one and one-half percent were due to carelessness on the part of the injured. These figures clearly demonstrate, if the concerns mentioned be considered as fairly representative, that a campaign of education is a most necessary part of the safety movement; and, in this connection, it is especially important to bear in mind the fact that a worker is for approximately two-thirds of a day, his own "boss," so that during the major portion of his time he can, by improper living, render himself unfit to perform one-third of a day's work.

From the preceding statement, it will at once be evident how closely right living, and with it sanitation, are interwoven in the safety movement; and, if it be further accepted, as it surely must be, that safety is in no small measure dependent on education, then the campaign is one in which all can and should participate, not only learning, but in turn imparting to others as opportunity offers, such knowledge as each possesses.

C. B. Auel

The Circle Diagram for Transformers

Vector diagrams constitute one of the best known and most simple methods of expressing the relations between voltage and current in alternating-current circuits. The more completely all of the operating conditions can be expressed by a few lines, the more successful may the diagram be considered. It is for this reason that the circle diagram for the induction motor has been so widely used—the performance of the motor, under all conditions of operation, is completely shown in a single comparatively simple diagram. This is possible by reason of the fact that the power-factor of the induction motor is constant for any given load, and is dependent directly upon the load.

The performance of a transformer and an induction motor are similar in many respects, but in this one respect they are in no wise alike, since the power-factor and load on a transformer are both independent of any characteristics of the transformer, and either may have any assignable value. Hence, although it is possible to draw a transformer diagram similar to the induction motor circle diagram, a separate diagram is necessary for each power-factor of the load.

This difficulty has been entirely obviated in the type of diagram described by Mr. Fortescue in this issue of the JOURNAL and, for want of a better name, designated as a circle diagram. In reality this diagram, by the simple expedient of plotting the vector loci, represents an infinite number of ordinary vector diagrams, including the primary and secondary volts, primary and secondary current, exciting current, and impedance, reactance and resistance drops, all in their correct phase relations, for all conditions of load.

One great advantage of this type of diagram lies in the readiness with which comparisons of vectors under different conditions of operation may be made, many of which are not possible when separate diagrams are drawn to represent the different conditions. For instance the statement that the secondary voltage lags behind the primary voltage more with a load having a power-factor of 90 percent lead than at any lagging power-factor appears rather startling on first thought, but this condition is readily apparent and is easily understood by the study of Mr. Fortescue's diagram.

It is hardly probable that this diagram will ever be used for the accurate determination of the regulation or other characteristics of a transformer in the way that the circle diagram is used for induction motors. For such purposes the charts by Mr. Peters, published in the JOURNAL for December 1911, are much more accurate. As a means, however, of securing a graphic comprehension of transformer operation under various conditions of load and power-factor these diagrams should prove most useful.

CHAS. R. RIKER

Electric Power in the Textile Industry

One of the greatest industries in the world both in value of product and in horse-power employed is the textile industry. Having been of slow growth and not being in any way spectacular, it is seldom that textile processes, developments or technical refinements are discussed in print except in the textile trade periodicals or in those papers circulating locally in the textile manufacturing districts.

Probably in no other great manufacturing field is competition so keen, with so many independent producers and, furthermore, with the added spur of international competition due to world-wide production and consumption. These conditions have forced rigid manufacturing economies, have required increased output without a lowering in quality, and at the same time the growing recognition of the rights of the workers to improved working conditions has required that machinery be made easier and safer to control, has promoted cleanliness and called for better lighting conditions. Electric power alone has made these improvements simultaneously possible; yet it has not been a haphazard development, but rather one resulting from slow and careful engineering analysis.

The textile industry affords a remarkable example of the advantages, and economies in the broader sense, obtainable by electric power for industrial drive. The profitable application of electric power begins with the ginning process, immediately after the cotton is picked in the fields, and extends throughout the succeeding manufacturing processes until the finished goods are delivered.

Two articles in this issue, by Messrs. Gelzer and LaMoree, describe the use of electric motors in ginning in different parts of the cotton raising country, and another article deals with the advantages of electric power for cotton mills making yarns and cloth. To the mill engineer this may be familiar matter, but as a careful analysis, showing methods of making comparisons with other drives, the article commends itself also to readers who are interested in similar studies in other industries. The correctness of Mr. Henderson's premises and conclusions is borne out by the practical unanimity with which the successful and prominent mill engineers and the builders of new mills have adopted electric drive, and by the large number of older mills that have wholly or partially installed electric drive.

D. S. BOWMAN

Safety and Welfare Work on a Large Scale

JAMES M. WOLTZ

Safety Director

The Youngstown Sheet & Tube Company

IN THE PRESENT PERIOD of active and wide spread [illegible] increasing interest of industrial establishments in the subject has [illegible] exploitation of numerous methods and devices which are the direct result of investigation and development along such lines. A curious fact in connection with this development has been that it is a direct outgrowth—not of demands on the part of their employees—but of an expanding realization on the part of manufacturers themselves that safety work would be a material asset in production due to the elimination or at least the reduction of accidents. In fact, as far as employees have been concerned, the work has been largely a matter of education, the average workman of an earlier period being very little impressed with the fact that measures were necessary for his protection.

J. M. WOLTZ

EARLY safety methods were for the most part haphazard in their application, due to the fact that in the ordinary plant they were left in the hands of individual foremen or persons locally in charge, with very little or no systematic central direction or supervision. However, the agitation of mill and railroad officials, the passing of laws, the creation of industrial commissions and the demands of workmen themselves, eventually resulted in the formation of safety organizations in plants and on railroads. With this came a desire to improve conditions then existing, and amongst the pioneers in establishing a "Safety Department," was the company with which the writer is connected. As an instance it may be cited that the first specially constructed "mill motors" for individual drive of steel mill machinery were built from plans and suggestions submitted by its electrical department. Prior to this time, it is true, there had been in use in some of the mills a few converted street-car type motors, but never before had a specially constructed mill motor been asked for and installed in a plant.

The adoption of the individual mill-motor was, in itself, an epoch in the electrical manufacturing world and, to the industrial world it was a blessing whose coming had long been awaited. Its adoption did away with long lines of shafting with their pulleys, belts and the numberless dangers connected with their use, not the least of which was the constant agitation of air in mills and shops, which was the cause of at least two occupational diseases.

THE BEGINNING OF THE SYSTEM

As was but natural, the duties of investigating accidents and adjustment of claims for injuries made those who were connected with the accident department particularly familiar with the causes of accidents, and it was possible in many cases for them to recommend means for their reduction. Accordingly it was but a natural result that a consolidation should take place between the accident and safety departments. Prior to this time committees of employes were largely the ones who looked after safety work, and these assisted the accident department in its efforts to call attention to dangerous places and protect its workmen. The Company maintained these safety committees, composed of such employes as department superintendents, assistant superintendents, and foremen. These committees were appointed from time to time, and served until a new committee was appointed to relieve them. They were expected to visit all the departments in the various plants and make their recommendations direct to the general superintendent, who in turn took up the matters as they affected the various departments, through the department superintendents. The committee recommendations covered the whole range of irregular and dangerous work practices, dangerous machinery, unprotected gears, fire hazards, sanitary conditions and the general welfare of the employes.

That this Company had made considerable progress in safety work as early as 1911, is attested by the fact that it was awarded a gold medal at the International Exposition of Hygiene and Safety, held at Dresden, Germany, in that year. This medal was awarded for an exhibit of drawings, photographs, models of safety devices and danger signs which were sent abroad especially for this exposition. That this was no empty honor will be readily recognized when it is recalled that the safety movement at that time was little more than a germ in this country. In the United States only a few of the largest manufacturing and railroad corporations had begun to realize the importance and necessity of accident prevention work. What little had been done had come about from a careful study of the array of figures and the results of the campaign for reduction of accidents that had been carried on in most of the continental countries of Europe, where the conservation of life and limb was already a matter of grave concern with many of the governments.

THE COMPLETE "SAFETY FIRST" ORGANIZATION

The rapid growth of The Youngstown Sheet & Tube Company necessitated the erection of many

large buildings equipped with modern iron and steel making machinery. These extensions called for the employment of a small army of workmen, and the safety work had grown to such an extent that it was thought advisable to organize a separate safety department which was placed in charge of the safe operation and installation of machinery, the super-

FIG. 1—BLAST FURNACE "D"
Provided with guard rails on walks, platforms, skip hoists, etc.

vision of work practices, sanitation, welfare, fire and police protection. This department has at its head a safety director, who is assisted by two safety inspectors, both of the latter being practical mill men,

FIG. 2—PROTECTION OF THIRD RAIL ON THE ORE BINS FOR USE OF LARRY-CAR

having received their training in the iron and steel business in the mills of the Company.

There is also a General Safety Committee composed of one of the operating officials, either the general superintendent, or his assistant, together with the chief surgeon, the special agent (an attorney-at-law), the safety director, three department superintendents, and a safety inspector for secretary. Safety and kindred matters of a general import that may affect the plant as a whole are taken up by this committee, and where there may be a disagreement as to the recommendations made in a safety requisition and when a department superintendent takes issue with the Safety Department as to the feasibility of carrying out its suggestion, these matters come up to the General Safety Committee for final settlement.

The Safety Department works in complete harmony with the Accident Department which is under the special agent, who also has charge of the Claim Department. The Accident Department sends a daily report to the Safety Department of the accidents of the preceding day, by departments, and also forms showing the history in a concise manner of each accident. These reports are thoroughly investigated to see if the accidents were avoidable and to fix the responsibility. The inspector who makes this investigation recommends means to eliminate the danger of

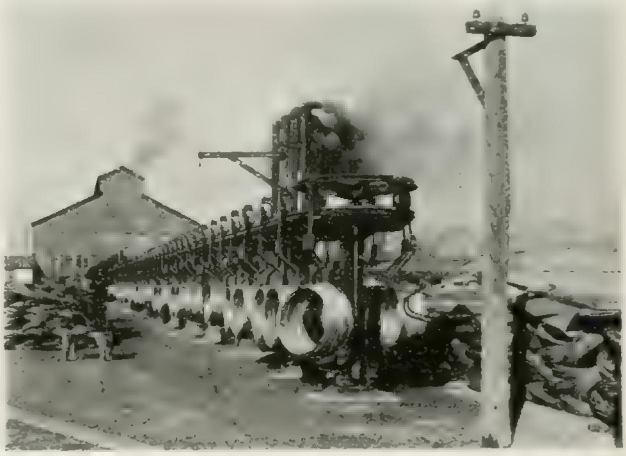


FIG. 3—ROD AND WIRE COOLING CONVEYOR
The sheave wheels are all protected.

a repetition of the accident and, when responsibility is fixed, recommendation is made for the discipline or discharge of the careless workmen, who may have caused an injury to himself or fellow workman.

Material assistance is given the Safety Department in its work by department foremen's committees. These are appointed in the various departments by the superintendents. These committees report directly to the department superintendent, who in turn submits the reports, with their endorsements, to the Safety Department for action.

Inspections are made daily by safety inspectors who cover the entire plant once each week. The property of the Company is divided into two sections and for one week an inspector will work the one section and the next week the other. One night each week is spent in the mill by each inspector.

Safety recommendations are made to the safety director, who approves or disapproves them. Those approved are given a serial number and are typewritten on a triplicate form. The original is sent to the general superintendent for his approval or dis-

approval. If the requisition is not approved by the general superintendent, it is returned to the Safety Department and, with duplicate and triplicate, is marked void and placed in the closed file. If the requisition is approved, when received by the Safety Department it is placed in an open file and the dupli-

FIG. 4—COAL CRUSHING PLANT FOR GAS PRODUCERS
All walks and stairways are guarded.

cate and triplicate forms are sent to the superintendent of the department affected, such additional notes as may have been made by the general superintendent being added. Matters involving the expenditure of a considerable sum of money or recommendations that require any extensive changes in work methods are first taken up with department superintendents so that there may be no friction in the execution of safety work.

Full and complete records are kept by the Safety Department of all requisitions and by this means a close check is maintained upon those still open. When a requisition is returned to the Safety Department as completed, the original is placed with the triplicate form, which has been returned by the department superintendent, and upon which is noted what action he has taken and the date the work was completed. The duplicate is retained for the files of the department superintendent. Returned triplicate forms are referred to the safety inspectors who make an investigation to see that the work has been done as recommended in the requisition and, upon the receipt of this form from the inspector with his report, the original and triplicate forms are placed in the closed file provided, of course, the work is as recommended. In the event that an investigation discloses that this work is not done according to the recommendation, the matter is called to the attention of the department head, with the request that it be so changed.

HOSPITAL AND MEDICAL STAFF

The Youngstown Sheet & Tube Company maintains two emergency hospitals for first aid dressings. One of these is in the main plant, the other at the rod and wire and conduit plants. As soon as a man is injured, no matter how slight the injury may be, he is given a form made out by his forman and requested to report at the emergency hospital for treatment. Here a complete record of his case is made on forms provided and, if he reports for subsequent redressings, note of these is also made on his record sheet. A new and modern hospital is now under course of construction near the North entrance to the main works that will give added facilities for the care and welfare of the employes.

The Medical Department is in charge of a chief surgeon who devotes his entire time to Company work. He has under him five male nurses, who are on duty covering the entire twenty-four hours and plans have been matured to have in addition three female nurses for service in the hospitals. Physical examinations are made of all persons who apply for employment and an examination of all employes who

FIG. 5—A WELL EQUIPPED BLAST FURNACE

entered the service prior to the time that the physical examination was instituted is being made as rapidly as conditions permit. Employes whose injuries are of a dangerous character are sent to the city hospital, where a ward is maintained for the use of Company employes.

In addition to the Company surgeon, there is employed a specialist in eye, ear and throat work. When an employe finds that a piece of foreign matter has entered his eye, he is prohibited by the Company rules from attempting to remove it himself, or to permit any one else, except the nurse at the hospital, to do so for him. This rule is necessary, to avoid the ever present danger of infection. All employes who are engaged in any work that endangers the eyes are required to wear goggles or face masks. These are provided by the Company, and are charged to the men to whom they are issued. If broken while at work they are replaced without cost to the employe. When the workman leaves the employ of the Company, he is given credit for the goggles when he turns them in. Trachoma, an infectious eye disease, was found in a number of cases of workmen who lived in the foreign section of East Youngstown, and the Company at once established a special eye hospital, to treat trachoma patients. All persons who were afflicted with this disease, whether employes, or simply residents of the village, were received and given free treatment. There were 36 cases under quarantine at one time. These cases were all confined in the hospital. At present there are no cases in quarantine and only 34 cases are being treated, so that the prompt measures adopted by the Company not only stopped a serious condition that had grown quite beyond the power of the local health officials to handle, but doubtless saved the sight of many of the persons who were treated.

FIG. 6—RUN-OUT TABLE, NO. 2 BLOOMING MILL
All gearing is completely covered.

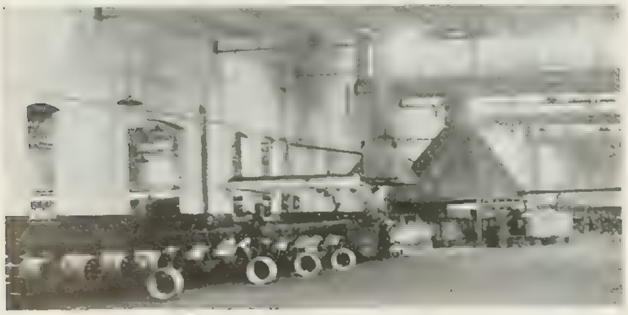


FIG. 7—GALVANIZING WIRE IN THE ROD, WIRE AND CONDUIT DEPARTMENT
The clear floor space around the machines minimizes the possibility of accidents.

In connection with the hospital service, metal stretcher boxes are provided at convenient points throughout the plant. They are painted red with green crosses, all numbered, each containing a regulation army-stretcher and a good wool blanket protected from dirt by paper bags. The Company also maintains its own ambulance service, having a motor, a horse-drawn ambulance and a buggy, the last of which is used to reach points that are difficult of access by the larger vehicles and to handle cases that are not severely injured.

FIRE PREVENTION

Fire reports are required from superintendents of departments for every fire that originates in the plant, from whatever source, no matter how trivial the damage may be. A card record is kept of all these fires, also of all fire extinguishers, hose houses and fire hydrants. The record of the extinguisher shows the make, when purchased, when tested and inspected. Soda and acid extinguishers are required to be refilled and inspected at least once in six months. Pyrene extinguishers are refilled as soon as used. All hose-houses are visited on the first trip of each patrolman on whose beat they are located, both day and night, the fire fighting equipment is inspected, and

FIG. 8—HIGH TENSION TOWER
Equipped with safety back ladder, angle iron railing around platform, and metal cover.

a report of its condition is made by each patrolman. Hose houses are provided with incandescent electric lamps that light automatically when the doors are

FIG. 9—GUARDS ON MOTOR-DRIVEN SHEET SHEARS

opened. Patrolmen are instructed to watch for unsafe and dangerous places, and for workmen who are careless or indifferent, and to assist in the care of injured workmen and at fires.

EDUCATING FOREIGN LABORERS

As can be imagined, the difficulty of the proper safeguarding of the 9 000 employes, who work in three separate plants, is no small undertaking and, besides the operating difficulties, there are other difficulties encountered, especially labor conditions which are general in the iron and steel industry. For instance, the large percentage of employes of foreign birth (71 percent in our case), who go to make up the total of the payroll, is a problem that requires constant watchfulness and care. When first employed, the foreign workmen may have been in this country but a few weeks and, in times when the mills are working to full capacity, it is more often days than weeks since the newly employed workman

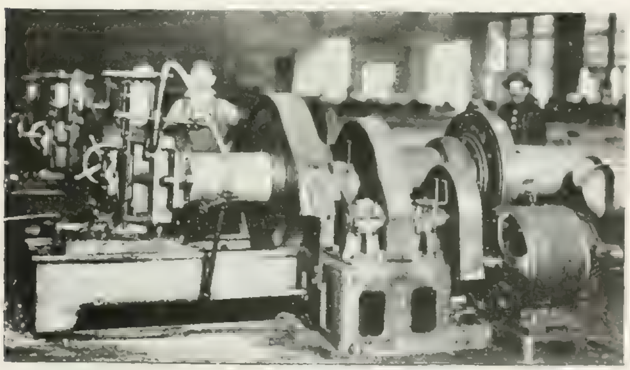


FIG. 10—GUARDS ON TUBE MILL CUTTING MACHINES

landed at Ellis Island. As is to be expected, it is the exception to find one of these men who can read, speak or understand a word of English. This means that the services of several interpreters are required. These interpreters are used to explain to the new employe the dangers of the work to which he may be assigned, and to secure the necessary data for his record of employment. Too often these men must be sent to work before the Company interpreter can make a full and complete explanation to them, and these duties then devolve upon the foreman who may

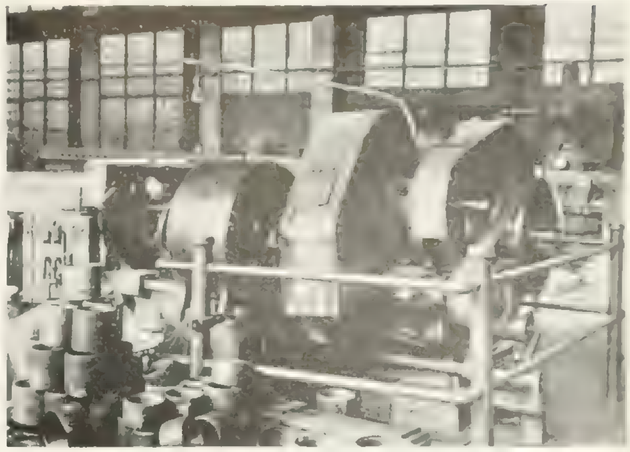


FIG. 11—GUARDS AND [illegible] MACHINE

be able to speak the new employes' language imperfectly or not at all.

The employment office maintained by the Company is located at its main entrance and there is a large sign, painted in English and several foreign languages, telling the men that the Company will employ only such men as are careful and willing to be careful of the safety of other employes. The fact that the various plants of the Youngstown Sheet & Tube Company are located near the main lines of travel between the Atlantic sea coast, where these new comers land, and the factories and farms of the great West and Middle West, makes these mills the stopping point of many newly-landed immigrants. Not only must this Company give these workmen their first lessons in industrial training, but it must also educate them in English and safety work.

It is these factors that make the educational part

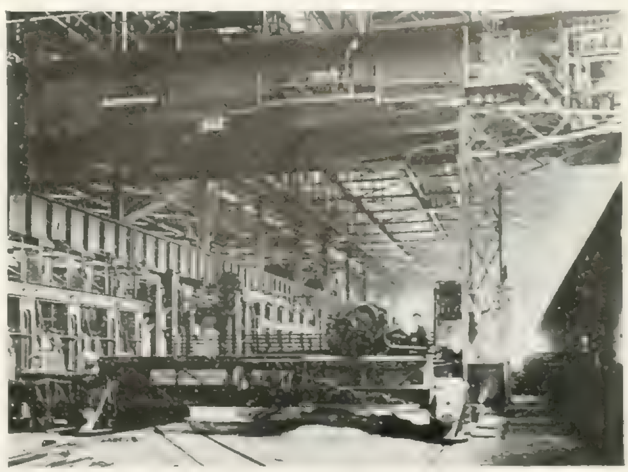


FIG. 12—OPEN HEARTH CHARGING CRANE AND OVERHEAD CRANE
Equipped with magnetic control, dynamic brakes and safety limit stops

of safety work so difficult in an organization as large as that of the Youngstown Sheet & Tube Company. This may be realized somewhat when it is noted that

this Company employs workmen of twenty-three nationalities, speaking about forty-two distinct dialects.

SPECIFIC DEVICES

The multitude of safe-guards that are used in the various plants of the Youngstown Sheet & Tube Company precludes a detailed description of each. A few of them, however, are shown in the accompanying illustrations. Those important devices in the adoption of which this company has been a pioneer or at least amongst the earliest of users are given in the following list:—

1—The trolley bar, replacing the trolley wire for crane runaways.
2—Magnetic control of all motors on cranes, making it impossible to abuse the crane or the motors by connecting the latter directly across the line.
3—The "Youngstown Safety Limit Stop" to prevent hooks from overloading and to stop hooks within an inch of travel in either direction by dynamic brake, when either light or loaded.
4—The dynamic braking method for ladle cranes, doing away with the troublesome mechanical brake.
5—The electric magnet for handling billets, pig iron and scrap.

FIG. 13—ONE OF NINE LOCOMOTIVE CRANES EQUIPPED WITH ELECTROMAGNETS

6—Covered gears over truck wheels and on overhead cranes.

SIGNS, PUBLICATIONS AND LECTURES

The company has a book of safety rules printed in English only, and a separate book of rules for crane operators. In addition to these books, there are a great number of safety and danger signs posted throughout the works, but these are simply incidental in the educational project, the main effort being to teach the workmen to be on the lookout for dangerous places and not always to look for a sign that will warn him of such places; in other words to train the employe to use his wits and be observant. Besides the permanent signs within the works there are at the entrances electrical signs which display mottoes that are changed weekly. These signs and slogans are painted in foreign languages in addition to the English. "Safety First" display cases are provided at the main entrances and at prominent points in the works. These cases are filled with photographs, drawings, cartoons, clippings, slogans, etc. They are arranged in an attractive manner and are frequently changed, so that a new set of exhibits is on view to keep up the interest of the men. In the promotion of safety and sanitation work, the Company has made

FIG. 14—THE WRONG AND RIGHT KIND OF SHOES FOR FOUNDRY MEN

The sign is prominently displayed in the foundry.

use of lectures and illustrated talks whenever possible. In 1911, the head of the American Museum of Safety, as well as the head of the iron and steel section of this Museum gave lectures to the workmen.

SANITATION

The sanitation is looked after by a special corps of men who scrub the latrines twice a day. These buildings are all provided with modern toilet facilities, are thoroughly screened, and are kept painted and in good general condition. Individual paper towels are supplied instead of the cotton or linen formerly used.

Drinking water is supplied from drilled wells, that are sunk several feet into bed rock and frequent bacteriological and chemical analyses are made of the water of each well. A fountain system has been planned to include all the various departments so

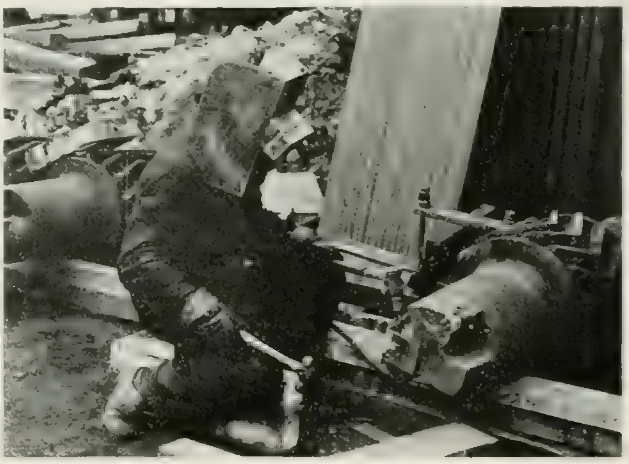


FIG. 15—PROTECTION FOR THE EYES, FACE AND HANDS IN ELECTRIC ARC WELDING

that water at an even temperature will be supplied to the employes in the mills, thus doing away with water buckets, coolers and other methods of cooling and supplying water.

Waste cans are provided throughout the mills for the deposits of rubbish, refuse, and the remains of lunches. A special corps of men are constantly at work in the mills and yards, to keep them in good condition.

Open overhead fans are used to cool the puddle mills while the tube mills, rod and wire mills and

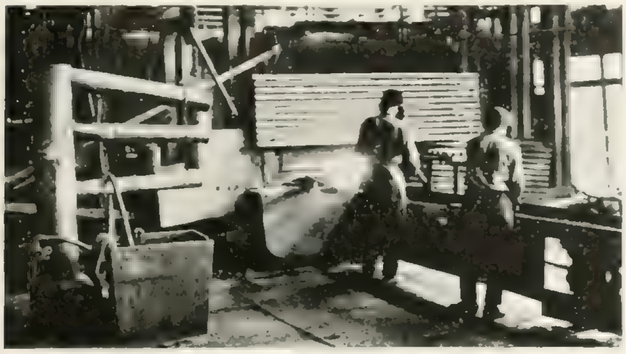


FIG. 16—VENTILATING SYSTEM AT THE TUBE-MILL FURNACES

open hearths are provided with air by conduit systems.

WELFARE PROJECTS

The welfare of employes enters directly into many company transactions; for instance, requisitions for machinery made by the purchasing department require that all proper safeguards must be furnished, and state that this feature will be taken into consideration in making purchases. This has

FIG. 17—CHIPPING.

The goggles and screen protect both the workman and his neighbors.

been a standard rule of the company for more than three years. Also the regular medical examination of employes has been of special benefit in showing the men where they are in need of medical attention and the particular things they should have looked after. Within the works the welfare of the employe is regarded wherever there is a possibility of danger:—foundry workers are required to wear congress shoes, which are supplied at cost to such as need them; carpenters, painters, linemen, riggers and sailors are provided with rubber shoes for use on loose or slanting surfaces; and in addition to these and many other such safe-guards, three pulmotors have been placed in the plant, which have been called into use a number of times, having proven their value long since by saving several lives that might otherwise have been lost.

Welfare projects have not been confined to working hours and the interior of the works by any means. Flower beds are scattered throughout the mills, and add cheerfulness to the work, giving a touch of beauty to a business that is at best dirty and unattractive. These flower-beds have been found to have a tendency to make the men want to keep the yards and shops cleaner than was the case without

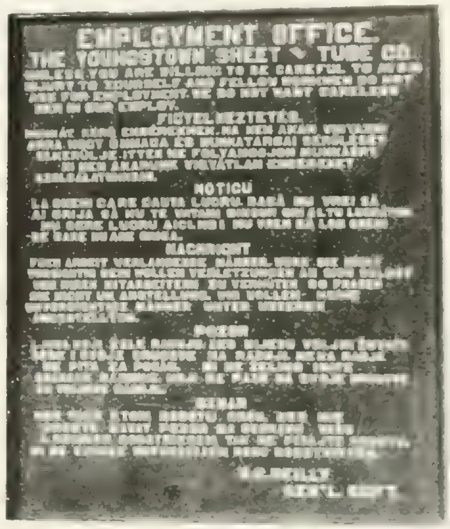


FIG. 18—SIGN ERECTED NEAR THE MAIN GATE.

them. Also inspection of home and living conditions has been begun as well as an attempt to clean up houses or homes found in bad sanitary condition, overcrowded or otherwise unfit for habitation.

CONCLUSION

Activity for the safety, health and welfare of its employes has developed in this Company a large and well established department which is as yet by no means perfect but which has for its immediate and ultimate aim the best interests of the individual workman. To this end, in addition to its own plans, suggestions are always gladly received and a committee meets monthly to consider such as are submitted, cash awards being made for suggestions which are regarded as of sufficient merit. Also the Safety Department is always glad to answer letters of inquiry from any source and furnish any information in its power.

A Central Station Analysis of Cotton Gins

JOHN GELZER, JR.

THERE are today 25 279 ginneries scattered throughout the southern states which in 1912 produced 14 313 000 bales of ginned cotton of 500 pounds each, and 6 104 000 tons of cotton seed. The value of this crop was nearly one billion dollars, representing the output from approximately thirty-four million acres of cotton growing land, most of which lies in ten southern states. Gins usually operate from two to four or five months during the year, beginning in September. The average number of bales per ginnery is 505. This is a small output for the modern gin and is due to the large number of small plants. As a result of the more general use of larger and more modern gins the average number of bales ginned per per establishment is rapidly rising.

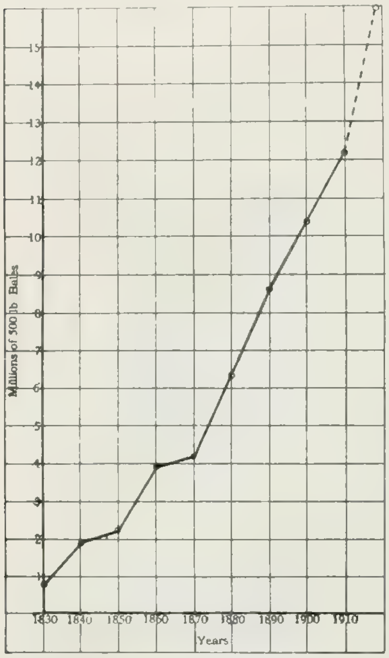


FIG. 1—CURVE SHOWING GROWTH OF COTTON GINNED IN THE SOUTHERN STATES

The dotted line represents the author's estimate.

PROCESS

When Eli Whitney invented the cotton gin he made it possible to separate the lint from the seed by machinery instead of by hand. Later inventions made possible elevating, cleaning and handling the cotton by power, as well as ginning, all under one roof and in one continuous series of operations. The standard ginning system of today removes the cotton from the wagon or storehouse by suction created by an exhaust fan, lifts it above a battery of gins and distributes it to the feeders, which in turn deliver it to the gins. From the gins it is delivered to a common lint flue through which it is conveyed to the battery of condensers by means of an air draft created either by brushes or by a fan. In the condenser the air is separated from the lint, which is formed into a continuous bat, and is automatically fed into a press, where it is pressed into bales and prepared for shipment. The seed is ejected from the gin, and may be handled by the exhaust fan if desired.

The success of a ginning outfit depends both on its ability to clean the seed cotton thoroughly before removing the seed and to handle it without damage to the staple. It is the present practice to install ginning outfits with two or more gins in a battery in a one or two story building. The equipment consists of either a belt distributor or a pneumatic elevator; flat plain or cleaning or upright cleaning feeders; single breast (plain) gins, or double breast (huller) gins of the single or double rib type; a double box press with steam, air or mechanical tramper and with screw, steam or hydraulic packers; and a screw conveyor and bucket elevator or a pneumatic seed handling arrangement or both, as may be preferred.

The brush system of ginning is driven usually from a line shaft and either a one story or a two story style of building may be used for this system. A 900 r.p.m. motor will be found satisfactory for belting directly to the line shaft.

With the air blast system the line shafts may be practically eliminated, and the gins directly connected to each other and to a short drive shaft by means of double universal couplings. A more compact arrangement is secured by locating this system in a single story building, as all the machinery in the ginning plant comprises a single unit, all the machines being dependent one on the other and the plant operating as a whole. With the equal gin speed secured

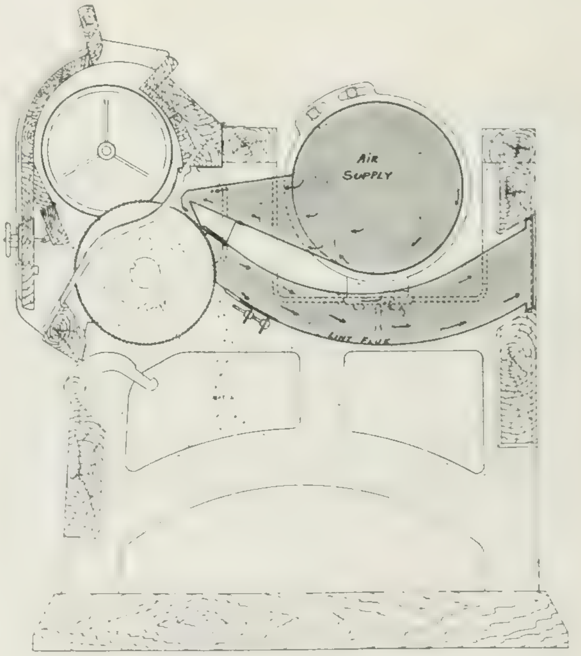


FIG. 2—INSIDE VIEW OF AIR BLAST GIN

Showing the air pipe and the arrangement of the parts. In this type of gin the brush, which ordinarily cleans the lint from the gin teeth, is replaced by an air blast directed against the gin teeth, which carries the cotton with it through the lint flue, as shown.*

by connecting all the gins together, the plant has a higher load factor than when separate drives are used. With the air blast system it is the usual custom to

*Figs. 2 to 7 inclusive were secured through the courtesy of the Lummus Cotton Gin Co., Columbus, Ga.

furnish one 1 700 r.p.m. motor with a fan on each end of its shaft and a pulley for belt connection to a common gin shaft. Systems having cotton house unloaders frequently have separate motor-driven fan units.

POWER REQUIREMENTS

Standard outfits are furnished with 70 or 80-saw gins which will handle from 250 to 600 pounds of lint per hour. In estimating on the power required for single gins with plain feeders and condensers it is the usual practice to estimate one horse-power for every ten saws, but in estimating the requirements for the complete gin outfit the power is estimated as one horse-power for every five saws, fan conditions and cotton being normal.

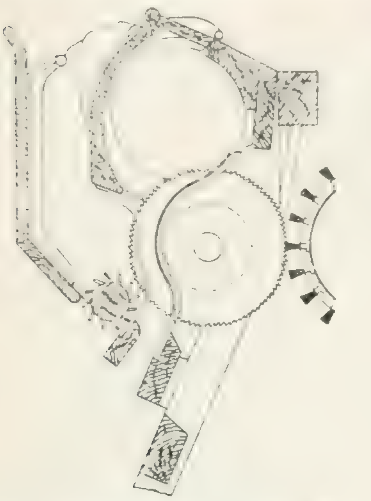


FIG. 3—CROSS-SECTION OF ROLL BOX ON A DOUBLE RIB, HULLER GIN

These huller gins are used where the cotton is hully, dirty, trashy and in bad condition, and are also used to gin long staple cotton. Cotton from the feeder passes into the outer breast where the saws catch and carry only seed cotton into the inner roll box where it is ginned as in the plain gin. The hulls and trash are thrown out of the outer breast and pass into a conveyor. Stones and other obstructions pass out with the hulls. This shows a brush gin, brushes being used to clean the lint from the gin saws in contrast to air blast for the same purpose.

Four 80-saw gins, therefore, would require 64 horse-power approximately. The power estimate, however, is only approximate, and necessarily must be, as this varies materially for different sections of the country. In some sections this amount of power is not required, while in some states the estimate is a little low. It has been found in the Mississippi delta that, owing to the extra weight of the cotton, heavier machinery is required and, consequently, about 25 percent more power is needed to operate ginneries in this section than with the so-called "hill cotton" or short staple cotton, but the above estimate as an average will be found a safe one.

TABLE I—COTTON PRODUCTION 1912

Number of bales produced	14 313 015
Aggregate value	$ 920 630 000
Weight of ginned cotton, lbs	6 556 500 000
Value of ginned cotton	$ 792 240 000
Weight of cotton seed, tons	6 104 000
Value of cotton seed	$ 128 390 000

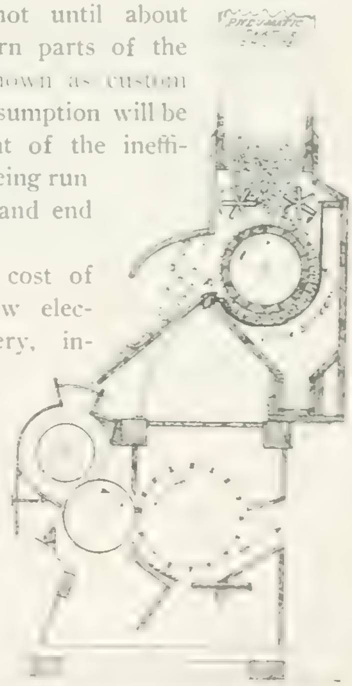
Standard ginneries of four 80-saw or four 70-saw outfits, according to the location and the kind of cotton ginned, will require from 50 to 75 horse-power and it is customary to recommend a 75 horse-power motor for driving these outfits, a 50 horse-power motor for the three gin outfits, and a 35 horse-power motor for two gin outfits. A 75 horse-power motor will be found satisfactory for five gin outfits, and a 85 horse-power motor for six gin outfits.

A gin usually operates during September, October, November and half of December. Conditions vary, however, according to location, gins beginning to operate about July 15 in southern Georgia and southern Texas and not until about October in the northern parts of the South. In what is known as custom ginning the power consumption will be found high on account of the inefficient running, the gin being run light at the beginning and end of the ginning period.

TABLE II—POWER REQUIRED FOR COTTON GINNING MACHINERY

MACHINE	REMARKS	HP
70 Saw Gin	No. used depends on cap. of plant	[illegible]
70 Saw Feeder	No. used depends on cap. of plant	0.8
40 in. Condenser	Used in 2, 3 and 4 gin plants	1.2
50 in. Condenser	Used in 5 and 6 gin plants	1.5
Conveyor	Used in 2 and 3 gin plants	1.5
Conveyor	Used in 4 gin plants	2.0
Conveyor	Used in 5 and 6 gin plants	2.5
Cotton Cleaner	All plants—if used	5.0
30 in. Double Fan	Used in 2 gin plants	17.8
35 in. Double Fan	Used in 3 and 4 gin plants	25.8
40 in. Double Fan	Used in 5 gin plants	34.4
45 in. Double Fan	Used in 6 gin plants	43.2
Screw Press	All plants—if used	[illegible]
Friction Tramper	All plants—if used	4.0

The approximate cost of a complete four 70-saw electrically-operated ginnery, including iron clad building, is $5000 delivered and erected.



[illegible]

Cotton enters from the elevator chute where fluted rolls pinch it and hold it until fast revolving picker drums beat the cotton free and against a metal screen removing dirt, trash, small stones, etc. Dirt and trash after passing through the screens are removed by a small screw conveyor to any convenient point within the gin house.

ANALYSIS

The usual charge for ginning a 500 pound bale is $1.25 in the East and $2.50 in the West. Prices vary, of course, according to conditions and competition. At 16 kw-hr. power consumption per 500 lb. bale and a flat rate of 2.2 cents per kw-hr. it required over five million dollars worth of power to gin the 1912 cotton crop. This output, figured back to $25 per continuous horse-power-year, represents an equivalent of 201 344 horse-power. For the 25 279 gins it is estimated there is required over one million primary horse-power. Many

of these gins are located in the rural districts, but it will be found that the tendency is to concentrate towards the towns, especially with the larger gins, as most of the cotton crop is being hauled to the towns or cities to be ginned and then the baled cotton disposed of. It is estimated that 50 percent of this gin load is within access of electrical energy, so that the central stations in the southern states should have connected to their lines approximately 500 000 primary horse-power in gins.

In comparing a steam-driven gin with an electrically-driven gin, where electrical energy is available, it will be found that the first cost of the steam plant will be greater and the depreciation very much more on account of the idle months and it has been estimated very closely that the annual savings in a four 70-saw gin, in interest and depreciation, is \$194 in favor of the electrically-driven over the steam-driven gin. On a gin which we have tested, in ginning 1 200 bales per season, this annual saving of \$194 represented a saving of 16 cents per bale ginned. The power consumption was 16 kw-hr. per bale at a rate of 2.2 cents per kw-hr., making the cost of power for ginning the cotton, 35 cents per 500 pound bale. The steam-driven outfit would have cost 51 cents per bale so that the estimated saving in power was 31.3 percent.

TABLE III—TYPICAL PLANTS TESTED

Plant	Horse-power of Motor	Size of Gin	Average Demand in Horse-power	Number Months Operated	Kw-Hr. per 500 lb. bale Ginned	Power Rate Cents per Kw-Hr.	Cost of Power per bale
A	50	3-70 Saw	48	3	15.2	First 750 Kw-Hr. 7c; all over at 2c	\$0.41
B	50	3-80 Saw	65	4¼	19.2	\$75 Min. per Month—Rate 1½c	0.28
C	75	4-70 Saw	70	4¼	20	2c	0.40
D	75	4-70 Saw	58	4½	13.5	3c	0.405
E	75	4-70 Saw	60	4	13.5	2.2c	0.297
F	75	4-80 Saw	69	4	......	50c per bale	0.50

TABLE IV.—GINNERIES—1912.

Number of ginneries	25 279
Average number running bales ginned per establishment	535
Number of months operated annually (Sept., Oct., Nov., Dec., Jan.)	3 to 5
Average primary horse-power required per five-saw gin capacity	1 to 1-2
Average size up-to-date gin now being installed	4-70 saw
Average primary horse-power required for above	50 to 75
Approximate number 500 pound bales ginned per season	1 200
*Time required to gin one 500 pound bale (by above)	20 minutes
Average electrical energy consumption per 500 pound bale ginned and pressed (from 15 to 18 kw-hr.)	16 kw-hr.
Rate per kw-hr. charged by central stations for electric power (no demand charge)	2.2 cents
Cost of electric power per 500-lb bale ginned and pressed	35 cents

*Regular time is 15 min. for clean cotton, 20 min. for good hully cotton, 25 min. for bad hully cotton and 30 min. for ball cotton.

From a number of tests made on electrically-operated ginneries it is found that the power consumption required per 500 pound bale ginned varies from 13 to 20 kw-hr. per bale, depending on the condition of the cotton and the location. It is safe to figure on 15 to 16 kw-hr. per bale. The rate varies from three cents to two cents per kw-hr. However, it has been found from actual tests on motor-driven gins by a large power distributor, that as an average a rate of 2.2. cents per kw-hr. will represent a profit to the gin and a reasonable profit to the distributor of electrical energy. One power distributor is making a flat rate of 50 cents per bale ginned

A chart is shown in Fig. 8 based on a charge of \$1.50 for ginning a 500 pound bale, separated into its component parts such as power cost, interest, depreciation and labor. Properly speaking, there should be a charge separated from the profit as repairs, but as this is a negligible quantity and in many cases is taken care of in the interest and depreciation account,

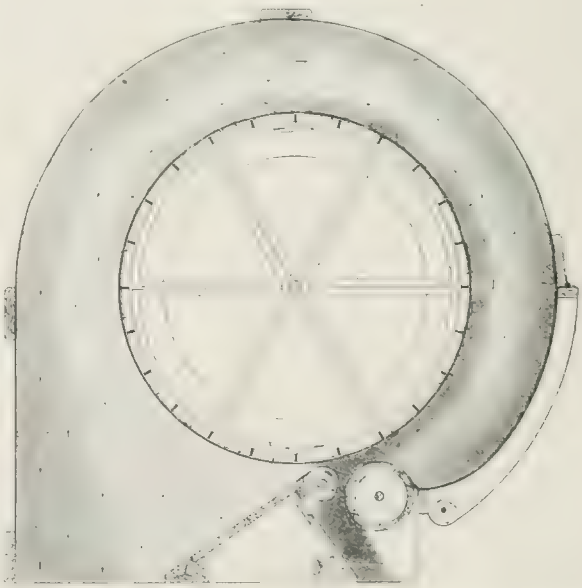


FIG. 5—SECTIONAL VIEW OF THE CONDENSER, SHOWING METHOD OF OPERATION

The shaded part shows the movement of cotton; the arrows indicating the direction of air, which passes through a screen on the revolving drum, carrying any dust or dirt with it, the dirt being removed from the ginnery by a conveyor.

we have made no attempt to separate this. Its value depends largely upon the care given the ginning machinery, but it should not amount to more than two cents per bale ginned.

In this particular case the ginnery handled 2 000 bales during the season with an average current consumption of 16 kw-hr. per bale. They paid for this at the rate of 2.2 cents per kw-hr. The plant represented an investment of $5 000 and they had a labor item fo $300 for the season. The interest and depreciation was figured at 15 percent and the price charged for ginning was $1.50 per bale. In this case the power cost per bale was 35 cents, interest and depreciation 37.5 cents, labor 15 cents and the profit 62.5 cents which would be reduced by the repairs per bale, which would amount to approximately two cents.

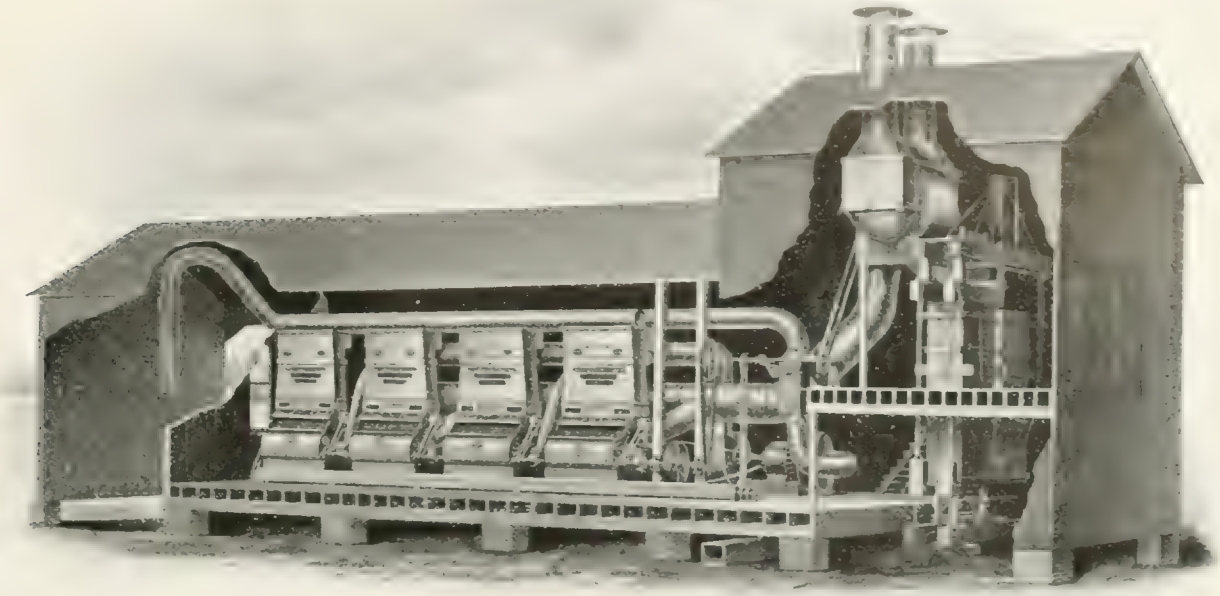


FIG. 6—A FOUR-GIN SYSTEM WITH AIR BLAST PLAIN GINS

The saw shafts are connected by means of double universal couplings, which allow disalignment of the gins, as well as providing for slight settling. The cotton is lifted into the elevator and distributed to the gins, by suction from the fan mounted on the left end of the motor shaft. The exhaust from this fan serves to carry away the cotton seed. The fan on the right end of the shaft provides the air blast, which removes the lint from the saw teeth and carries it through the large flue to the condenser at the top of the building. From the condenser the cotton is fed in a smooth, even bat into the press, at the extreme right.

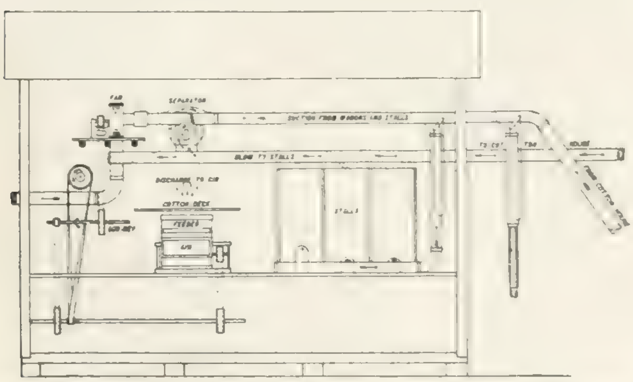


FIG. 7—DESIGN AND LAY-OUT FOR AN UNLOADING OUTFIT WHICH MAY BE USED FOR EITHER A LARGE OR SMALL PLANT

This is interesting to the extent that it gives a comparison of the different component cost parts which go into the ginned bale. The percentages are given as percentage of the total charge of $1.50 for ginning.

CONCLUSION

It would appear that there is a considerable load available within access of the lines of central stations in the South in operating cotton gins. Though this load was looked upon for many years, and is still looked upon by some central stations, as undesirable on account of the operation, facts do not bear this out. As a matter of fact central stations can take on gin loads at a profit, and at the same time make it profitable to the ginnery to use central station power. The interest and depreciation on the investment of the central station for the idle months is small and for the average gin installation is amply covered by $50 per year.

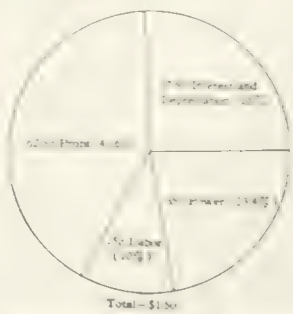


FIG. 8—DISTRIBUTION OF COSTS OF GINNING COTTON

Electric Power for Textile Mills

John S. Henderson, Jr.

PERSONAL CONTACT with the managing and operating heads of textile mills has developed methods of treatment of this subject that have not only aroused interest but secured action. As the treasurers and superintendents are accustomed to think in terms of money and mechanics, the subject is treated from an investment standpoint and in mechanical terms. The treasurer wants to know what return will be secured on the money invested. The superintendent wants to know whether the speed-torque characteristics of the power offered suit the productive machinery in his mill.

THE CARDINAL factors which should govern the choice of a power scheme for a new mill are:—

1—Speed-torque characteristics of the power for best quality and greatest quantity of product.
2—Cost of the power.

The quality of the product is considered first, because the cost of the power does not differ very widely with the different methods now in use.

SPEED-TORQUE CHARACTERISTICS

The inherent speed-torque characteristic of the productive machine is the first point for analysis. For the larger part of the productive machinery, the torque (force tending to turn the main shaft) should not vary in intensity within one revolution of the main shaft of the productive machine. The speed should be steady—or uniform. It should not increase or decrease in speed suddenly within one revolution of the main shaft. Looms, moreover, demand the application of a power whose speed is itself uniform, although the torque demand may vary 50 percent or more. For looms an individual motor can be designed and built to absorb satisfactorily the shock due to the sudden change of load. The slip of a belt may have a reasonable cushioning effect. The modern loom is built with a friction drive which acts as a shock absorber.

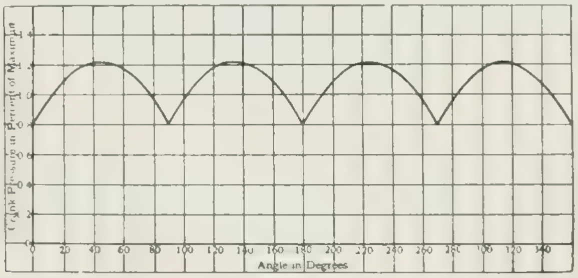


FIG. 1—TURNING EFFORT DURING ONE REVOLUTION OF THE CRANK

In general, the productive machinery requires a uniform speed and a uniform torque applied to the main shaft. Electric motors which secure power from steam turbines meet the desired conditions.

SPEED CHARACTERISTICS OF RECIPROCATING ENGINES

The engine usually seen in a mechanically driven mill is a cross-compound engine with cranks at right angles. Let us assume equal loads on the two cylinders. Suppose the pressure of the steam uniform throughout the stroke, the connecting rod to act always parallel to the center line of the engine, and the moving parts to be without weight, the total pressure tending to turn the shaft would resemble the curve, Fig. 1. The pressure tending to turn the shaft around varies from a maximum to a minimum and the speed of the shaft is pulsating. In reality, the steam pressure is constant for only a part of the stroke, the connecting rod does not move parallel to the center line of the engine, and the moving parts have weight. A flywheel of large diameter with a heavy rim is used as an expedient to reduce the pulsations in speed. The speed must rise and fall to make use of the "flywheel effect." Exact tests have shown speed pulsations up to four percent on cross-compound engines. Tachometer readings on the main jack shaft in any mechanically driven mill will show material pulsations in speed. There is this inherent undesirable speed condition in any reciprocating engine.

TRANSMISSION BY SHAFTING AND BELTING

There are two cardinal points to consider in such a transmission system:—

1—Shaft torsion.
2—Alternate tightening and slacking of belts.

The elasticity of steel shafting is such that when a long shaft supported by a number of hangers is started the part to which power is applied turns before the free ends. The reaction causes the free ends to "hunt" for equilibrium. When the torque of the productive machinery is variable, as in a weave shed, equilibrium is never realized. In a spinning room the uniform torque required and the large flywheel effect in the productive machinery tends to steady the shaft, but, because of the inherent pulsating speed of the engine and the alternate tightening and slackening of belts in the main and subsidiary drives, equilibrium is never reached even in the spinning room.

Tachometer readings in a number of mechanically driven mills show that the shafting varies instantaneously in speed within one revolution of the shaft by amounts varying from three percent to more than 30 percent. In one mill, for instance, the speed of a shaft in a weave shed varies six percent at the driven part and 20 percent at the free ends within one revolution. On this shaft, assume that a pulley at the free end, whose average surface speed is 1 000 feet per minute, drives a loom by means of a belt. Necessarily, there must be a slip of the loom pulley due to the sudden load changes. But the belt itself is not being supplied with uniform speed. There is an excess slip between driving pulley and belt due to frequent changing of the surface speed of the pulley from 900 to 1 100 feet per minute almost instantaneously, as shown in Fig. 2.

The use of an electric motor driving short lengths

of shafting, as in Fig. 3, would maintain reasonably uniform surface speed of the pulleys on the line shafts. The acceleration in surface speed of the driving pulley from 900 to 1 100 feet per minute may often

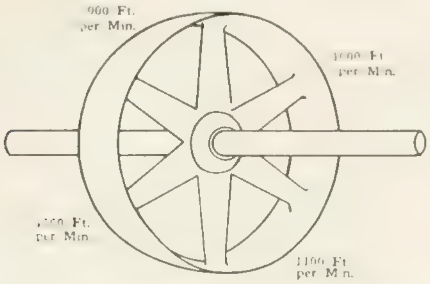


FIG. 2—DIAGRAM INDICATING THE RAPID CHANGES OF SPEED WITHIN A SINGLE REVOLUTION OF THE PULLEY

occur just when the loom pulley should slip. Excessive back lash in the loom belts is present in most mechanically driven weave sheds and is apparent.

COST OF POWER

Five present methods of driving a mill requiring a peak load of 2 000 indicated horse-power are here considered:—

I—Two 1 000 horse-power cross-compound engines and mechanical drive.
II—Two 750 kilowatt high pressure turbines and group motor drive.
III—One 2 000 horse-power combination cross-compound engine and low pressure turbine and combined drive.
IV—One 750 kilowatt high-pressure turbine, and one 750 kilowatt bleeder turbine, with group motor drive.
V—Purchased power and group motor drive.

In this example the steam conditions are assumed to be:—

Plant I—150 lbs. gauge pressure, 26 in. vacuum.
Plants II, III and IV—150 lbs. gauge pressure, 28 in. vacuum.

First costs include complete power plants and all auxiliary equipment necessary to drive the main shafts in the mills. Economizers are not included.

Operating costs are based on results realized in Fall River and New Bedford mills, where good condensing water is available, some published records, and results from turbine plants now installed.

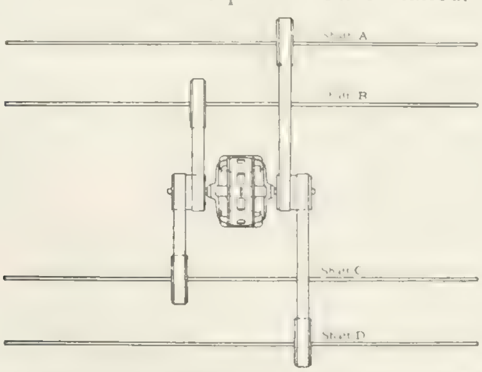


FIG. 3—A METHOD OF OBTAINING FAIRLY UNIFORM SPEED BY THE USE OF MOTOR AND SHORT LENGTHS OF SHAFT

The mills in Fall River make print cloths. The New Bedford mills make fine goods. Good soft coal in most of these mills costs in the neighborhood of $5 per ton on the boiler room floor, which is the price assumed. The power plants for mechanical drive usually consist of two engines belted direct to the main line shafts in the mill. The no-load losses of the engine, shafting and belting are usually about 25 percent of the total load when all machinery is running. The corresponding loss under load is about 35 percent of the total.

The first costs, given in Table I, vary but little with the locality. The cost of coal per ton will vary with the locality, modifying this item. For instance, with good soft coal at $3.00 per ton, for the isolated plants the cost per indicated horse-power per year would be less than shown in the table by about 19 percent. A change of ten percent in the cost of central station power per kw-hr. will change the total cost per year (or the cost referred to indicated horse-power in the engine) by about eight percent.

In Plants I, II and III, heating and slashing costs were not considered, as the amount of slashing

TABLE I—RELATIVE COSTS OF POWER FOR A PEAK LOAD OF [illegible] INDICATED HORSE-POWER, CORRESPONDING TO 1 270 KILOWATTS AT SWITCHBOARD

Item	Plant I Engines	Plant II Turbines	Plant III Combination Engine & L. P. Turbine	Plant IV Bleeder Turbine	V [illegible] watt hour
First cost	$1[illegible]0 000	$125 000	$11[illegible]0	$[illegible]	$[illegible]
Fixed charges—12 percent	15 [illegible]	15 000	1[illegible]800	15 [illegible]	[illegible]
Labor	5 000	5 000	4 500	[illegible]	[illegible]
Coal or Energy	21 [illegible]0	20 000	18 100	1[illegible]	[illegible]
Supplies & repairs	2 000	2 000	2 25[illegible]	2 [illegible]	[illegible]
Total per year...	44 7[illegible]	42 000	38 650	41 600	[illegible]
Cost per indicated horse-power per year...	22.37	21.00	19.32	[illegible]	[illegible]

and heating varies with the locality. For comparison with Plant IV, which includes a turbine to bleed steam for slashing and heating, assume:

Slashing—2 000 lbs. steam per hr.—1 200 hrs. per year. Slashing and Heating—6 500 lbs. steam per hr.—1 500 hrs. per year.

The total would be 610 tons of coal per year if steam were taken from boilers.

GENERAL REMARKS

The costs given in Table I are actual. The coal consumption is based on the average of a number of mills. Labor and supplies are based on actual results. Obsolescence is cared for on a twenty-year sinking fund basis. The estimates for slashing and heating are based on tests and actual costs for Fall River and New Bedford territory. The costs of electrical apparatus are based on equipment that has been installed. The kilowatt-hour price of purchased power is assumed for the sake of comparison.

The drives chosen are as nearly as possible comparable group electric and mechanical drives. The losses of a plant under load between the indicated horse-power of the prime mover and the brake horse-power at the shaft of the productive machine are approximately the same for mechanical drive and for turbines with group electric drive.

THE ADDITION OF EQUIPMENT TO EXISTING PLANTS

Additions of low pressure and bleeder turbines to plants already installed often pay a fairly good net return on the money invested, even where no increase in power is contemplated. In cases where additional power is needed, handsome returns are possible.

Low Pressure Turbines—The reason why relatively maximum economy results from adding a low pressure turbine to a cross-compound engine can be observed by referring to Fig. 4. This provides a basis by which to compare the amounts of energy realized by different prime movers. The chart is based on one pound of dry saturated steam at 165 lbs. absolute pressure, entropy 1.56, the volume of which is 2.753 cu. ft. One curve shows the relation between expansion and pressure. The other shows the relation between total heat and pressure.

Economy in a steam engine is realized by using, to as great a degree as feasible, the property of ex-

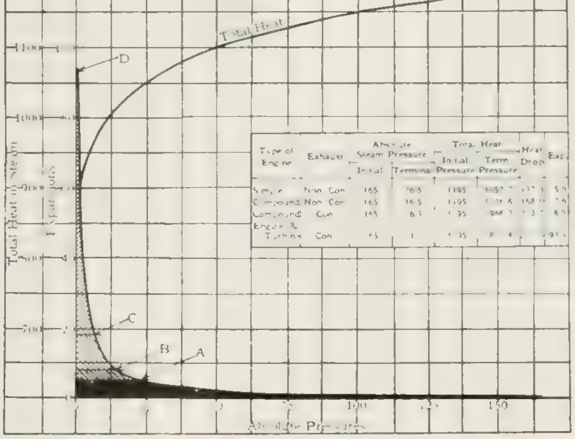


FIG. 4—COMPARISON OF STEAM EXPANSIONS OF FOUR TYPES OF PRIME MOVERS

A—Simple non-condensing engine.
B Compound non-condensing engine.
C—Compound condensing engine.
D—Engine and low-pressure turbine.

pansion of steam with drop in pressure. There are commercial and engineering limitations to the use that can be made of this property of steam with a compound engine.

As may be seen in the table in Fig. 4, four types of prime movers are considered: the simple non-condensing engine, the compound non-condensing engine, the compound condensing engine and the combination of compound non-condensing engine and low pressure turbines or high pressure condensing turbine—the same figures in the table will apply for either case of the last condition mentioned. In all of the above engines and combinations assume that the steam follows the adiabatic line. For simplicity of explanation further assume that one pound of steam is admitted per stroke, in each engine. Considering the simple non-condensing engine, assume that cut off occurs at 20 percent of stroke, that release takes place at the end of the stroke, and that the exhaust or terminal and the release pressure are the same. Then the expansion ratio is five and so the volume of the cylinder is 5×2.753 or 13.76 cubic feet, as 2.753 cubic feet is the specific volume of dry steam at 165 pounds absolute pressure. Now the quality of steam at release is about 89 percent, which gives a specific volume of $\frac{13.76}{0.89}$ or 15.45 cubic feet and the pressure corresponding to this specific volume is 26.5 pounds absolute which is the exhaust pressure for the simple, non-condensing engine.

Considering the non-condensing compound engine, with a cylinder ratio of 3 to 1, assume that the exhaust or terminal pressure is 16.5 pounds absolute, that release occurs at the end of the stroke, and that the exhaust and the release pressures are the same. As this exhaust volume of the steam is 24.05 cubic feet and the quality of the steam at exhaust is 87 percent which gives a cylinder volume of 0.87×24.05 or 20.93 cubic feet, then the expansion ratio is $\frac{20.93}{2.753}$ or 7.6.

Considering the condensing compound engine, assume a cylinder ratio of 4.5 to 1 and cut off at 25 percent of stroke; then the expansion ratio is $\frac{4.5}{0.25}$ or 18. When the same release and exhaust pressure conditions are assumed as before the volume of the low pressure cylinder is 18×2.753 or 49.56 cubic feet. Now the quality of the steam at release is 83.3 percent, which gives a specific volume of $\frac{49.56}{0.833}$ or 59.4 cubic feet and the pressure corresponding to the specific volume is 6.3 pounds absolute, which is the exhaust pressure of the compound condensing engine.

Considering the combination of compound non-condensing engine and low pressure turbine or high pressure condensing turbine, assume an exhaust pressure of one pound absolute. The quality of steam at exhaust will be 77.6 percent and the specific volume corresponding to one pound absolute pressure is 333 cubic feet which gives an actual volume at exhaust, for one pound of steam admitted to the engine, of 0.776×333 or 258.3 cubic feet. Then the expansion ratio is $\frac{258.3}{2.753}$ or 93.9.*

For a compound condensing engine cutting off at 25 percent stroke, the cylinder ratio to meet this condition would be $94 \div 4 = 23.5$ to 1. Such a machine would be a commercial impossibility regardless of design.

The work done by the non-condensing compound engine and low pressure turbine is proportional to the area from 165 lbs. to one lb. absolute and 94 expansions, as compared with 18 expansions in the 4.5 to 1 compound condensing engine referred to above. In short, the greater economy realized by a low

*The figures for the different engines of total heat, both initial and terminal were determined from an entropy temperature chart and checked from Marks & Davis steam tables.

pressure turbine and engine is due to an extension of the use of the expansive property of steam beyond the point that is feasible for a compound engine.

From Fig. 4, it is apparent that the work (and the heat drops) in the non-condensing compound engine and the low pressure turbine are nearly equal, if the engine terminal pressure is 16.5 lbs. absolute.

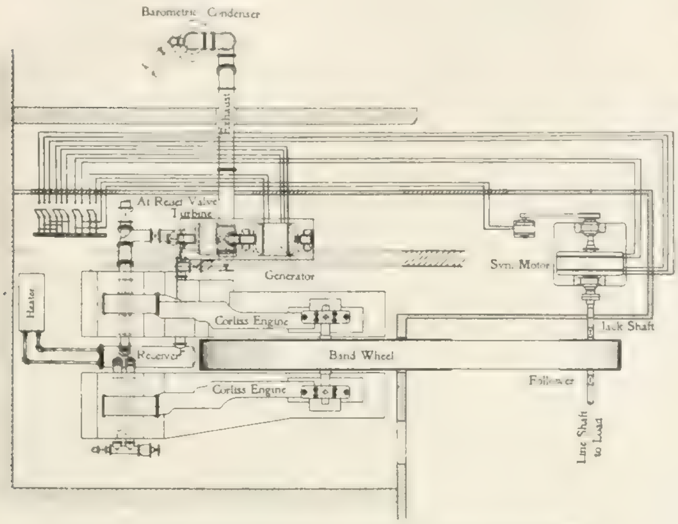


FIG. 5—SYNCHRONOUS BALANCER COMBINATION SET

Synchronous Balancer—In operating a low pressure turbine with a compound engine and mechanical drive, there are desired:—

1—Maximum economy from the triple expansion system.
2—Application of turbine speed characteristic to mechanical transmission system.

These results are secured by means of a synchronous motor called a balancer. A method of connecting engine, turbine and balancer is shown in Fig. 5. The synchronous motor is electrically tied to the turbine and mechanically tied to the engine. It performs two duties:—

1—With change of absolute or relative electrical and mechanical load, it automatically proportions the load between engine and turbine insuring maximum economy.
2—It supplies a uniform torque to the jack shaft thus giving a uniform speed to that part of the mechanical transmission system.

Bleeder Turbines—Where steam for heating, bleaching or slashing is required, a bleeder turbine may prove a good investment. A bleeder turbine takes high pressure steam, which does work in the high pressure section, automatically bleeds the amount of steam required by the heating system at a lower pressure, by-passing the remainder, which performs more work, through the low pressure section to the exhaust. Thus, a part of the power becomes a by-product of the necessary heating system. The principle is shown in the temperature-entropy diagram, Fig. 6, where the heat units in areas *A*, *B* and *C* are necessary for mechanical power and the heat in the area *D* is necessary for the heating system. That part of the mechanical load represented by the area *B* becomes a by-product of the necessary heat *D* for the heating system. Whatever the value of *D*, the proportion $A:B::C:D$ always holds true.

The relative conditions may change from time to time, in which case more or less power may become a by-product of the heating system. In Plant IV, the saving in coal per year compared with Plant II, was $400 per year by making a small part of the power a by-product of 12 percent of the total steam.

Bleeder turbine installations are making a handsome net return on the investment in all the cases where the conditions are favorable. A large mechanically-driven mill with a bleachery attached is in most cases an excellent possibility for a bleeder turbine installation. This turbine shares with the high pressure and low pressure turbine the characteristic of uniform turning moment, and consequent uniform speed applied to the shaft of productive machines. The non-condensing turbine extends the advantages of a bleeder turbine in that, where the heating demand equals or exceeds the relative power requirement, all of the power is a by-product.

CENTRAL STATION POWER

Central station power may be termed "turbo-electric power" as practically all central stations doing a power business are equipped with steam turbines. The rates for large amounts of power bring the cost per unit of power and the total yearly cost almost equal to the costs in the various designs of isolated plants, unless a material amount of power can be made a by-product of a heating system. The speed-torque characteristics of central station power meet the requirements of the productive machines. A distinctive advantage of central station power is that there is left free for use in the business a large amount of capital. The frequency of turn-over and the value as a trading medium of this free capital often appeals strongly to the prospective power user. An attendant distinctive advantage is the readiness with which motors lend themselves to the reorganization of a mill providing the process in the mechanically driven mill do not properly dovetail; overtime

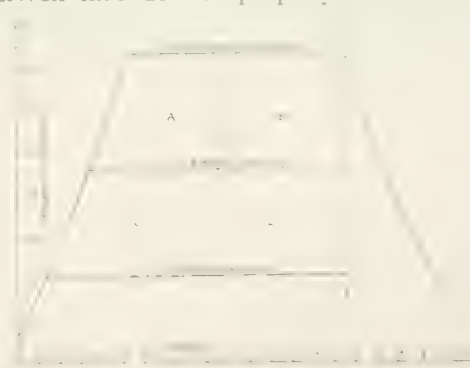


FIG. 6—TEMPERATURE ENTROPY DIAGRAM
Showing economy realized by the use of a bleeder turbine in connection with the heating system.

power costs are also a minimum. In some cases, the inherent characteristics of the existing power plant machinery or productive conditions may make impractical the use of low pressure or bleeder turbines. Any change in the power equipment of such a mill would naturally lead to the use of central station power.

On this basis of the costs in Table I, central station power in a new mill will cost less than any of the isolated plants and will leave free for use as capital in the basiness \$80 000 to \$95 000. The 2 000 horse-power isolated plant with combination of low pressure turbine and engine compared with central station power at one cent per kilowatt-hour will save approximately \$6 600 per year for an investment of \$80 000.

ATTENDANT CONCLUSIONS

Power, the source of which is a steam turbine, transmitted by motors—

1—Supplies the proper speed-torque conditions required by the productive machines.
2—Costs a minimum amount per unit of product.

Compared with engines and mechanical drive, the advantages of turbo-electric power are—

Better quality of product.
Probable increased quantity of product.
Less expensive power per unit of product.

The results realized by mills where electric power is installed have proved the value of turbo-electric power.

The Cotton Industry in California

C. D. La Moree

THE IMPERIAL VALLEY is located in the southeastern corner of California, 187 miles from Los Angeles and 102 miles from San Diego. This valley and the northern part of Mexico adjacent to it produced approximately 9 000 bales of cotton in the year 1912, and in 1913, 20 000 bales. On the basis of approximately one bale per acre it is estimated that the 1914 crop will be at least 40 000 bales.

At the present time a number of gins are installed in the valley located in Calexico, El Centro,

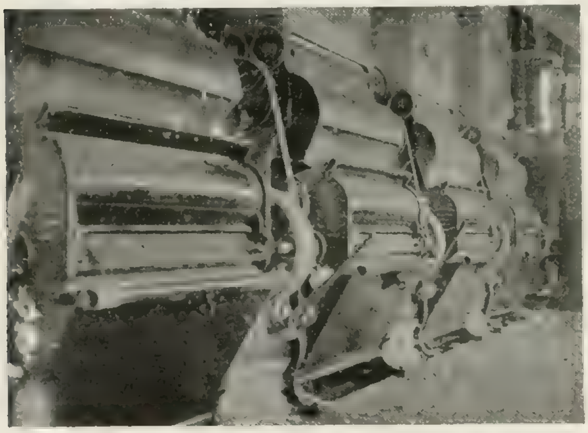


FIG. 1—ONE OF FIVE SETS OF MURRAY GINS OF FOUR STANDS EACH, ALL ELECTRICALLY DRIVEN

Imperial, Brawley, Holtville and Seeley, where the Imperial Valley Oil & Cotton Company have been the pioneers of the industry. With the rapidly growing production in this section, these gins will be taxed to their full capacity, making it advisable to investigate present conditions with a view to the maximum production from the present equipment and to the establishing of the best type of ginning installations for the future.

A typical arrangement of gins is shown in Fig. 1. In this plant a 50 horse-power, three-phase, 60 cycle, 2 200 volt, 850 r.p.m. motor is belted to a line shaft, which in turn is belted to the four stands of ...d the cleaner, blower, air compressor and con... The compressor—which is six by six in.—...shes the air for the cotton presses which are located on a platform at the front of the building. There are at present six sets of Murray gins of four stands each in operation in the valley, all but one of them electrically driven.

An excess of shafting indicates a waste of power; also, the warm climate, having a marked effect on belts, makes the present arrangement unsatisfactory as regards belt adjustment. Accordingly an endeavor has been made to develop a beltless gin, but the large amount of cotton which of necessity would ultimately clog up any gears and the question of dust makes the belting of individual motors to the different machines the simplest and—in the opinion of the writer—the best solution of the problem. The best arrangement up to the present therefore calls for individual motors driving twin stands of gins; one motor to each twin stand and one motor for driving the brushes. The air compressor, cleaner and blower will be individual drive.

The belting of individual motors to the twin stands of gins eliminates two twisted belts, whereas under the old arrangement, belt adjustment was impossible. Further, by means of this change, the overall length of the building which houses the gins may be reduced approximately twenty feet, eliminating the space for the large motor and switching devices, the smaller motors all being suspended from the ceiling or arranged for wall mounting. A considerable saving over the former power requirements may be anticipated due to the elimination of twisted belts and practically all of the line shafting.

The amount of power required to gin a bale of cotton has been estimated at 19.2 kw-hr. The cotton ginning record for November 1913, however, shows 3 704 bales ginned with an average consumption of electricity per bale of 16.5 kw-hr. The power for these gins comes from the lines of the Holton Power Company, who have a network of lines, covering practically all of the valley that is settled. Distribution of power is at 15 000 volts, three phase, 60 cycles, the 50 horse-power motors in the gins all being 2 200 volt machines. The cotton seed is taken care of by means of an 80-ton mill at El Centro and a 60-ton mill now under construction at Calexico.

The Engineering Evolution of Electrical Apparatus–VI

THE EVOLUTION OF THE POLYPHASE INDUCTION MOTOR (Cont.)

R. S. Feicht,
Manager of Engineering,
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WOUND COIL ROTORS

THE NEXT step by the Westinghouse Company toward providing an induction motor for other than constant speed service was made when the coil wound rotor with collector rings, external resistors and controller was introduced in America about the year 1900, although this type had been used quite extensively in Europe several years before. The motor developed by the Westinghouse Company was later known as the type "F," Figs. 13 and 14, and consisted of a standard type "C" primary with special coil wound rotor. The rotor punchings were of the partially closed slot type; the winding was of the bar and end-connector or wire-wound coil type, forming a close coil arrangement, tapped at three points 120

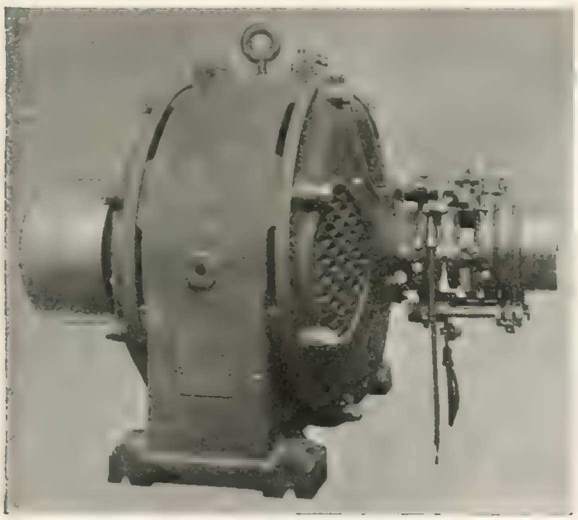

FIG. 13—TYPE F POLYPHASE INDUCTION MOTOR—PERIOD 1901 TO 1906

Made on type *C* frame and having all parts, excepting rotor and one end bracket, interchangeable with the corresponding parts of type *C* motor.

degrees apart for delta connection or opened at six points 60 degrees apart and cross-connected to form a star winding. External resistors and controller were provided to permit variation of the resistance in the rotor circuit, such variation in resistance causing the speed to change from zero to maximum. With such a motor, many applications for which the type "C" motor was unsuited were satisfactorily covered, such as hoist, crane and elevator service.

An interesting application of the wound secondary type of polyphase induction motor was made in 1902 by the Westinghouse Company for the Miami & Erie Canal Transportation Company, in connection with four locomotives for use in towing canal boats. Each locomotive weighed twenty tons and was equipped with two 80 horse-power, three-phase, 25 cycle, 200 volt, four-pole induction motors, with wound rotors of the same phase and voltage as the primaries. The control was arranged for normal operation of the locomotive under load at half maximum speed, with the two motors connected in cascade and developing 80 horse-power total. It was also arranged for the operation of a single motor at full speed driving the locomotive without load. These locomotives met their specifications satisfactorily, but were not used excepting in an experimental way because the boat propul-

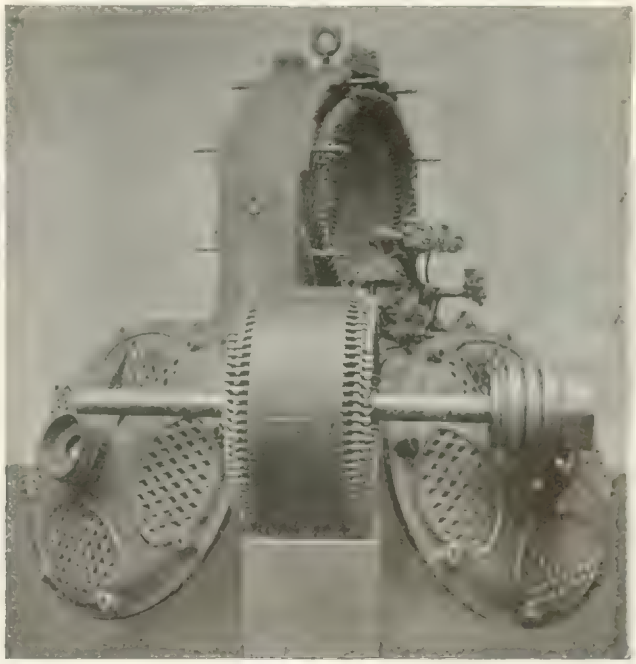

FIG. 14—DETAILS OF A TYPE F WOUND-ROTOR POLYPHASE INDUCTION MOTOR

The wound primary and one end bracket are the same as for corresponding size of type *C* motor.

sion system, as a whole, proved a failure. It was the intention to use them to tow fleets of six or seven boats in the Miami & Erie Canal at a speed of approximately three miles an hour, but it was found on that trial that, due to the narrowness of the canal, the boats of the fleet banked up the water ahead of them to such an extent that the level of the canal was lowered successively by each boat in the series until the last one in the fleet practically ran aground.

This was the earliest commercial application by the Westinghouse Company of the polyphase wound rotor induction motor for traction purposes. A number of applications have since been made in connection

with mining and other small locomotives. The most interesting one by far will be the locomotives that are now being built by the Westinghouse Company for the Norfolk & Western Railway Company. This equipment will consist of twelve 270 ton locomotives, each made up of two half units; each half unit will be driven by four three-phase induction motors of the wound rotor type. The primaries and secondaries of

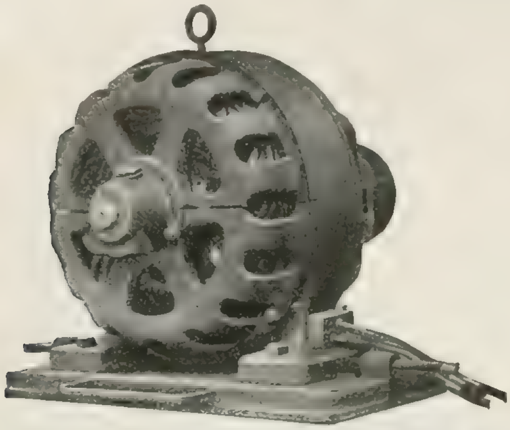

FIG. 15—TYPE CCL POLYPHASE INDUCTION MOTOR—PERIOD 1905 TO DATE

the motors will be of the two-speed type and provided with single windings adapted for connecting either for four or eight poles. On the slow speed connection each locomotive will have a *continuous capacity* of 2 640 horse-power, at a speed of 14 miles per hour, and on the high speed connection a *continuous capacity* of 3 000 horse-power at 28 miles per hour. They will be operated from an 11 000 volt single-phase trolley circuit through step-down transformers and phase converters which supply the motors with low voltage polyphase current.

A short time after the introduction of the type "F" motor for varying speed service, a demand arose for a constant speed motor which could be started under load without undue disturbance to lighting circuits from which it might be operated. The type "C" motor was designed to give a starting torque equivalent to full load with current in the line approximately two and one-half times full load current, or other starting torques up to maximum starting torque with a proportional starting current in the line and at a power-factor of approximately 60 percent. In some cases, where the regulation of the generators or line was poor, this performance was very unsatisfactory and some provision had to be made for overcoming it. This was accomplished by the use of the type "F" motor provided with a special self-contained starting resistance and controller. With such a combination, the motor could be started up under any torque up to maximum without exceeding the line current which would be required when the motor was operating at speed and developing the same torque.

In the foregoing we have traced the development polyphase induction motor by the Westinghouse any through the period covered by the life of Tesla patents, which expired May 1, 1905. It was recognized that on the expiration of these patents the field would be thrown open to other manufacturers and sharp competition with motors having more limited characteristics than the type "C" motor would result. Accordingly, steps were taken to prepare for this competition when it should be met. During the latter part of this period the production of the polyphase induction motor by the Westinghouse Company had been confined to the type "C" motor and its variations. This motor was in reality a pioneering piece of apparatus. It represented the highest development of the art for its time, and was admirably adapted for the important duties it had to perform in educating the public in the application and the use of a new class of apparatus. Its sturdy mechanical construction, large overload capacity and unsaturated magnetic circuits gave it the large factors of safety necessary to withstand the abuse it was subjected to in its early applications. The direct-current motor had its commutator and brushes to give the distress signal when it was misused, but the type "C" motor, free from commutators, collectors and brushes, had nothing to indicate its abuse unless it were overloaded to the point of blowing the fuses or opening the circuit breakers, or causing its windings to smoke from excessive heating. Many were the cases where these motors had been installed on circuits having double the voltage for which the motor was wound. Often they gave no direct indication of trouble under these conditions and the error was discovered only after an investigation was made following a complaint that the motor had a very low power-factor. In other instances, the motors have been found operating for a long period under load connected to circuits of half normal voltage and with no signs of distress excepting the temperature of the windings running above normal. Judging from the reports received from numerous installations of these motors, it is quite probable that a considerable percentage of them were operated under excessive continuous overloads. In the writer's knowledge a number of them have actually carried double load continuously without difficulty. These conditions usually

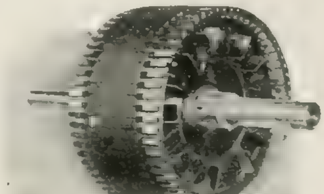

FIG. 16—SECONDARY OF TYPE CCL POLYPHASE INDUCTION MOTOR

were not discovered until the facts were developed by applying to the same service motors of later design, more closely rated—that is, motors whose actual rating corresponded more nearly to the name plate marking.

In addition to the continuous overload capacity, the type "C" motor also had an intermittent capacity greater than later motors. This was due to the fact

that it had comparatively massive magnetic cores and frames with large heat storage capacity. It is this characteristic of the motor that later designs could not well duplicate as it depended entirely upon the mass of material in the motor. It is obvious that a motor with such large overload factors and representing the first design of its type, would not necessarily be the cheapest and best design possible and the one best suited to meet keen competition.

FIG. 17—WOUND PRIMARY OF TYPE CCL POLYPHASE INDUCTION MOTOR

Showing partially closed slots and "dropped-in" type of windings.

During the latter years of the period covered by the Tesla patents a demand had arisen for a motor with higher power-factor and efficiency than the type "C," and one which would cost materially less. In order to meet this demand and provide for the increased competition, the engineers of the Company, profiting by the experience gained from previous designs, both here and abroad, developed the type "CCL" motor. This new motor, while it involved no fundamental differences in principle, was, at the same time, quite different in both mechanical and electrical design from the type "C" motor, although the weight of the motor was from 40 to 50 percent less. The general appearance of the "CCL" motor is shown in Fig. 15. The principal physical features in which the two motors differed are as follows:—

The primary frame and brackets were lighter in construction and better adapted than the type "C" for thorough ventilation of the windings. The magnetic core of the motor was narrower. The distance between bearings was much shorter. This latter feature, in connection with the lesser weight and flywheel effect of the rotor, added materially to the factor of safety of the shaft which was maintained at approximately the same diameter as the type "C" for a given rating. The secondary windings through the core were made up of a larger number of bars and of smaller cross-section than were used in the type "C" construction, Fig. 16. The punchings of the primary core for low voltage motors were of the partially closed slot type, which was a radical departure from previous designs, Fig. 17. The windings for low voltage motors up to about 75 horse-power were of the so-called "dropped-in" type; that is, the coils were wound on a form, but not completely insulated. The partially closed slots were insulated with a fibre cell open at the top. Through this opening the individual turns of the winding were threaded into the slot which was afterwards sealed over. The ends of the coils outside of the core were then insulated so that the resulting winding corresponded in effect to one formed of completely insulated coils with open slots. Above 75 horse-power the low voltage windings were in general, either of the bar and end-connector or the strap type. In the latter case, the partially closed slot had the tooth tip projected from one side only, thus permitting the conductors to be dropped into the slot the same as in the wire-wound type. As a rule, the high voltage windings were placed in open slots, although in the largest sizes the partially closed slot was at times used. In such cases, however, each coil was completely insulated over the straight portions and one end and then split at the other end and straightened out; afterwards it was shoved through the slots and the open end re-connected and insulated.

The partially closed slot construction was adopted for the low voltage "CCL" motors, because it had been used successfully in England and on the Continent. The European Westinghouse Companies had found it impossible to introduce the type "C" design in competition with the partially closed slot construction and, therefore, had abandoned it in favor of the latter. The advantage of this construction is that by its use a motor with better performance, lighter weight and lower cost could be built, than by using open slot construction. Other conditions being the same, the partially closed slot tends to improve the efficiency of an induction motor by decreasing the losses in the surface of the secondary core caused by the high frequency flux passing into it from the primary teeth. It also decreases the effective air-gap and, further, permits a reduction in the actual air-gap, both of which tend toward producing higher power-factors. In the case of the "CCL" motor, the smaller clearance be-

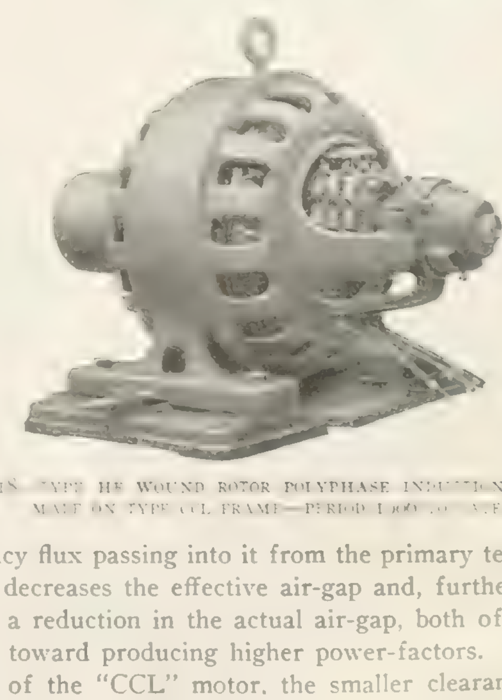

FIG. 18—TYPE HF WOUND ROTOR POLYPHASE INDUCTION MOTOR, MADE ON TYPE CCL FRAME—PERIOD 1900 TO [illegible]

tween the primary and secondary was justified from a mechanical standpoint by the increased rigidity of the rotor construction due to the short bearing centers and heavy shaft noted above.

The type "CCL" induction motor was designed as a general purpose motor, the same as the standard lines of direct-current motors. In its application some services were encountered for which it was unsuited, and which, therefore, required a specially designed motor. A similar condition had been met in the application of direct-current motors to street railways, steel, cement mill and other service where it had been found necessary to develop special types on account of the severity of the service and the requirement that the motors operate practically continuously and be easy to repair in case of break down.

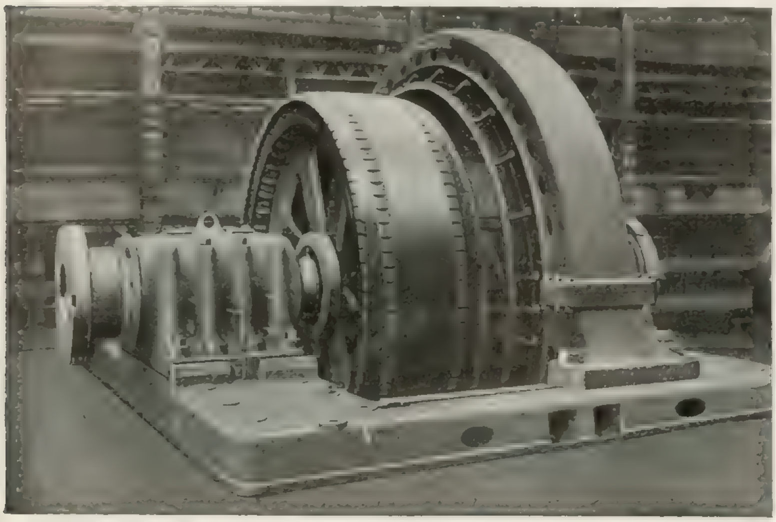

FIG. 19—A 3 200 HORSE-POWER WOUND-ROTOR INDUCTION MOTOR

For operation of 14 inch merchant mill at the plant of the Indiana Steel Company. Note stator is slid aside for access to rotor.

A notable feature of this rotor construction is the sectional banding plates which permit removal of parts of the winding without disturbing the band, excepting over the coils affected.

The rapid growth in the application of special induction motors in steel mills from the time they were first introduced, illustrates in a striking manner the superiority of alternating-current motors for this class of service. The present overwhelming preponderance of induction motor as compared with direct-current motor applications in steel mills is a direct result of the survival of the fittest system. Previous to 1904, practically all electric motors in steel mills were of the direct-current type, the reason being that under the conditions prevailing at that time the direct-current otor was the best for the service. Electrification of olls was in its infancy and electric motors were, al, used only for the minor applications, such cranes, hoists, fans, roll-tables, etc. For this service the direct-current motor was better adapted on account of its being more flexible in its application; further, it had been in the market longer than the induction motor and had been used successfully in street railway service, so that it was in no sense an experimental heavy duty machine. As a matter of fact, many of the early direct-current steel mill motors installed were standard railway motors, provided with bases or feet.

After the minor electrical applications had passed the experimental stage, and the economies of the electric drive were thoroughly appreciated, steel mill engineers turned their attention to the larger problems involved in main roll electrifications and some very creditable installations of direct-current motors resulted. An example of such an installation made in 1905 by the Westinghouse Company may be seen at the Edgar Thompson Steel Works where two 1 500 horse-power, 220 volt direct-current motors are used for driving light rail mills. The success of these installations pointed to the further possibilities of economies in electrification of the larger mills, such as were being driven by steam engines of capacities varying from 2 000 to 6 000 horse-power. It was recognized, however, that the direct-current motor could not be used economically for this service on account of the expense involved in generating, transmitting, switching and utilizing the heavy low voltage direct currents required. The polyphase induction motor offered the solution for the problem and was accordingly adopted,

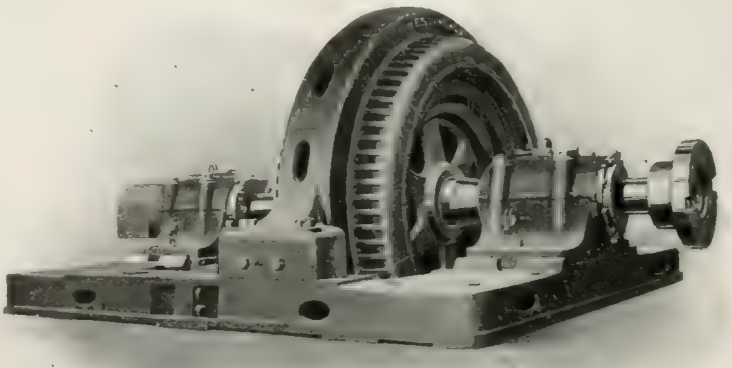

FIG. 20—A 650 HORSE-POWER HF WOUND ROTOR INDUCTION MOTOR

For operation of finishing stand of 14 inch merchant mill at the plant of the Indiana Steel Company.

first in some of the smaller mills, and later in the larger ones. In these applications special motors of the wound rotor type were used, varying in size from 500 up to 6 000 horse-power. One of the first installations of this kind was made in 1906 by the West-

inghouse Company for the operation of a re-rolling rail mill in the plant of the Illinois Steel Company. It consisted of two sets of wound rotor motors of 1 800 horse-power capacity each, adapted for operation from 83 to 125 r. p. m., the higher speed being obtained with a single motor in operation, and the lower speed with the two motors connected in tandem. In later applications of induction motors to rolling mill operation where single speed motors were not satisfactory multi-speed motors were used with the primary and secondary windings arranged for different numbers of poles. A number of such installations were made, a typical one being the 2 500 horse-power, 25 cycle, two-speed, 6 600 volt, 32 and 26 pole motor put in service in 1910 at the plant of the Indiana Steel Company for the operation of a 12-inch merchant mill.

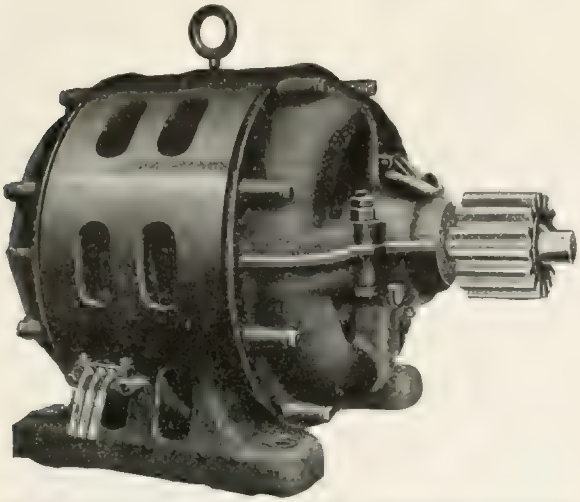

FIG. 21—TYPE MS POLYPHASE INDUCTION MOTOR FOR HEAVY DUTY SERVICE—PERIOD 1909 TO DATE

The most common construction for the large steel mill induction motor is one with a wound rotor, but arranged for single speed, Figs. 19 and 20. These motors are applied usually with flywheels. The wound rotor construction is adopted both to provide for easy starting conditions and also to permit the use of external resistance in the rotor circuits, so that the energy stored in the flywheels may be utilized to assist the motor in carrying peak loads.

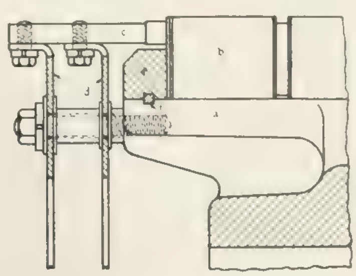

FIG. 22—PARTIAL VIEW OF SECONDARY OF TYPE MS MOTOR, SHOWING CONSTRUCTION OF WINDING

The introduction of large induction motors into steel mills necessitated the use of alternating-current plants and distributing systems in addition to the direct-current systems which were required for the direct-current motors in the minor applications. The disadvantages of these mixed distributing systems in the mills directed the attention of steel mill engineers to the polyphase induction motor for the smaller applications where direct-current motors formerly had been used exclusively. As a result, a demand was created for an induction motor which would give the the same class of service as the special direct-current motor. Thus the polyphase induction motor which had entered the steel mill field in only a small way previous to 1903 or 1904, and against a powerful competitor, the direct-current motor, had in the course of five or six years made rapid progress toward supplanting its rival almost completely.

In order to meet the demand for a special mill motor a new design, later known as the type "MS," Fig. 21, was developed by the Westinghouse Company and placed on the market early in 1909. This motor was in general similar to the type "C' motor and although it weighed considerably less, it was better adapted than the type "C" for mill service. The characteristic features of its construction were the massive well-ventilated frame, the rugged split brackets and bearings, both being interchangeable end for end, the heavy shaft, the open slot primary with coils completely insulated before assembling, and the special secondary resistance rings, Fig. 22, designed with liberal radiating surface and bolted to both bars and rotor spider so as to withstand the shocks incident to severe mill service. Since its introduction the type "MS" motor has been used very extensively for constant speed service in steel mills, cement plants, brickmaking plants and many other industries requiring motors of extra rugged construction. This motor, however, was not adapted for all of the applications in heavy mill service as there were many cases where a varying speed or reversing motor was required. To fulfill this requirement the Westinghouse Company placed upon the market, in 1910, a line of wound rotor motors later known as the type "MW," Fig. 23. This line was made with similar parts, interchangeable with the "MS" motor, a matter of considerable importance where both types of motor are used in the same plant.

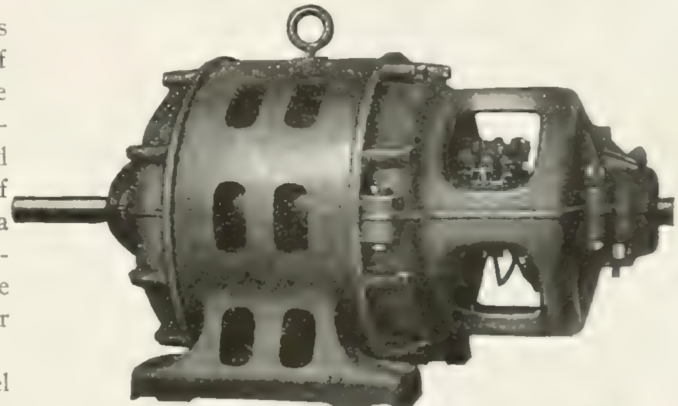

FIG. 23—TYPE MW WOUND-ROTOR POLYPHASE INDUCTION MOTOR—PERIOD 1910 TO DATE

Made on type *MS* frame and having many parts interchangeable with corresponding type *MS* motor.

About two years ago, at the suggestion of prominent steel mill engineers, the Westinghouse Company

brought out another line of wound secondary motors, with mechanical characteristics similar to the direct-current mill motor, because this particular mechanical design had proven very satisfactory in mill service, and also because it was desired to have a motor that

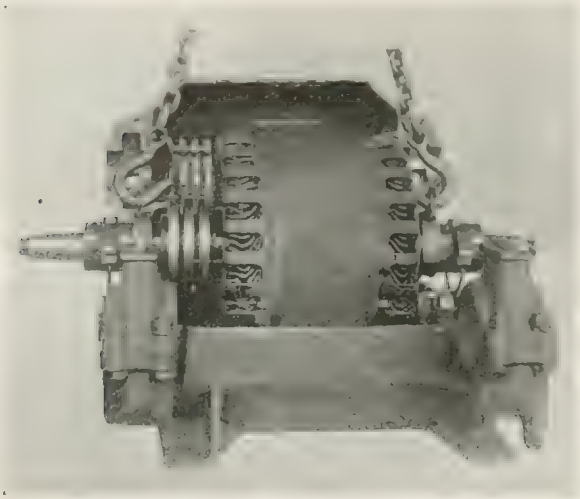

FIG. 24—TYPE MA POLYPHASE INDUCTION MOTOR

Showing the frame opened and primary and secondary being removed. Note the construction of the primary ring which is similar to the ring used with large type "C" motors, such as shown in Fig. 11.

could be readily substituted for the direct-current mill motors on roll-tables, cranes, etc. This motor, known as the type "MA," Fig. 24, shows a striking resemblance to the well-known direct-current mill motor. The application of this motor to date has not been as general as was anticipated, but there is every reason for believing that it has an important place to fill and will be used extensively in the near future.

The more recent developments in polyphase induction motors for general service conditions have been in the nature of refinements in design, looking to-

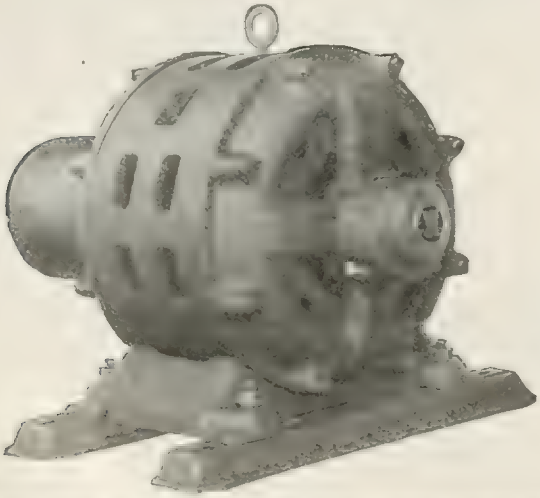

FIG. 25—TYPE CS POLYPHASE INDUCTION MOTOR WITH ROLLED STEEL FRAME

The feet and slide rails are made of pressed steel.

ward reduction in manufacturing costs and improvements in electrical and mechanical characteristics. ...he design of the "CCL" motor in 1904 and 1905, ...ortant advances were made in the art, and ...r of mechanical features were perfected that looked quite promising; for example, the pressed steel construction for bearing brackets, feet of primary frame and rails; the rolled steel construction for frames; the frameless construction; the magnetic wedge; the cast-on secondary end ring, etc.

The type "CCL" motor, although it served exceptionally well the purpose for which it was designed, was the subject of some criticism when first introduced on account of the use of the partially closed primary slot construction with dropped-in type of winding. This construction had been used successfully abroad for a number of years previous to its introduction in this country and no doubt the reason for its not meeting with unqualified approval here at first, was the fact that it involved novel winding features which were not thoroughly understood by the user. However, the advantages of this construction far outnumbered its disadvantages, considering the state of the art at that time, although improvements made since then permit the use of the open slot construction with completely insulated coils in all but the smaller sizes of motors, below about five horse-power, where its use is still almost universal. It is of interest

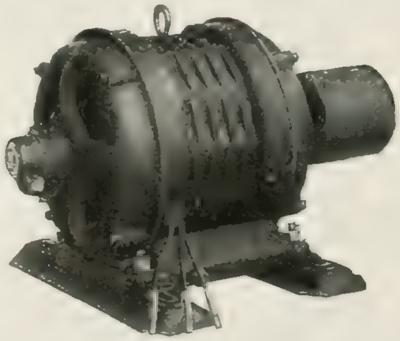

FIG. 26—TYPE CS POLYPHASE INDUCTION MOTOR OF THE FRAMELESS CONSTRUCTION

This motor has end rings, brackets, feet and rails made of pressed steel.

to note here that the criticism of the "CCL" partially closed slot construction was short-lived and the motor has been manufactured by the Westinghouse Company in larger quantities than any previous design and is, after ten years, still on the market.

The rapid growth in the application of the polyphase induction motor, and the consequent increase in the volume of motors manufactured during the period covered by the "CCL" type suggested to the designer the feasibility of a less expensive and, at the same time, better mechanical construction, permissible only where large manufacturing quantities justified the expense of special tool equipment. With the foregoing conditions in mind, the designing engineers set about to produce a polyphase induction motor which should take advantage of all the improvements in the art. The result was the design of the type "CS" motor, shown in Figs. 25 and 26. In the smaller sizes up to about five horse-power capacity, this motor is of the frameless construction, Fig. 26, with partially closed primary slots and dropped-in type of primary winding. The primary core is riveted between heavy pressed steel end rings to which are also riveted a pressed steel

foot. The brackets are also of the pressed steel construction. The primary punchings are polygonal in shape and are assembled with sections of the laminations staggered to increase the radiating surface.

In sizes above five horse-power and including about 20 horse-power standard speed, the frameless construction is also used. The primary core, however, is of the open slot type of construction with completely insulated form-wound coils. Instead of the usual fibre wedge found in open slot machines, a magnetic wedge is used, combining the advantages of both the open slot and partially closed slot types of primary. The magnetic wedge is a three-piece construction of drawn metal parts, Fig. 27. The center of the wedge is made of a strip of brass and is flanked on each side by a steel strip, the whole being insulated from the primary teeth when being inserted in the slot by means of fullerboard strips. The secondaries of the "CS" motors up to about 20 horse-power capacity have windings similar to those of the smaller "CCL" motors. These windings consist of the usual insulated copper bars on the ends of which are pressed segmental copper punchings, the number of which can be varied to form resistance rings of the required proportions.

In the larger sizes above 20 horse-power a primary frame is used, Figs. 25 and 28. This frame is

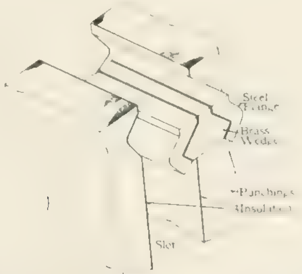

FIG. 27—SKETCH OF MAGNETIC WEDGE USED IN THE PRIMARY SLOTS OF TYPE CS AND THE SECONDARY SLOTS OF TYPE MW POLYPHASE INDUCTION MOTORS

made of universal plate steel stock rolled into the required form. To this frame is riveted a pressed steel one piece foot. The brackets are made of cast iron. The primary core is of the standard open slot type construction. It is made up of laminations punched from sheet steel narrower than the diameter of the internal bore of the frame, thus giving a lamination square in general appearances but with the corners punched round to fit the frame bore. This form of punching was adopted on account of its being economical in material. Its use in connection with the rolled steel frame without internal ribs to support the punchings gives a primary construction of minimum weight.

The secondary winding of the larger "CS" motors is quite novel in construction, as it is formed with copper bars with copper or alloy resistance rings cast to them, Fig. 29. Instead of the bars being insulated from the core, with the usual fullerboard wrapper, or cell, they are placed in the slots which latter are filled with cement. Afterwards, the rotor with bars cemented in the slots is placed in an oven and baked, producing a solid construction with the bars separated from the core with fireproof insulation.

The type "CS" polyphase induction motor, as it is manufactured to-day, represents the highest devel-

FIG. 28—WOUND STATOR OF TYPE CS POLYPHASE INDUCTION MOTOR

opment in the art of induction motor design, both from an electrical and mechanical standpoint. Its pressed and rolled steel constructions, its magnetic wedge and indestructible rotor, place it in a class by itself.

In this rather limited historical sketch of the polyphase induction motor, the writer has confined himself exclusively to the developments made by the Westinghouse Electric & Mfg. Company, the data not having been available for a general treatment of the subject covering the developments made by all manufacturers. In this county practically all of the radical developments were made during the life of the fundamental Tesla patents in which period the field was limited to

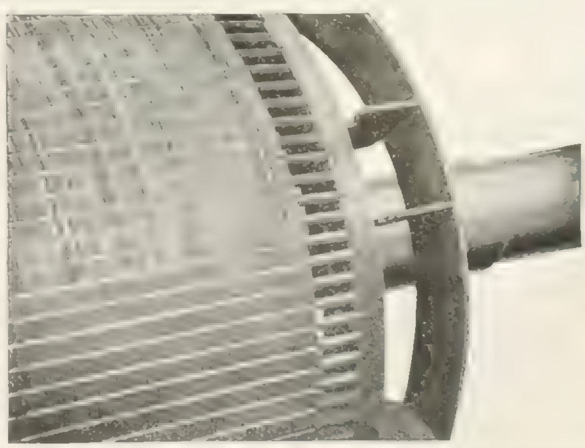

FIG. 29—DETAILS OF ROTOR OF TYPE CS POLYPHASE INDUCTION MOTOR

Showing cast-on resistance rings and ventilating plate.

licensees under those patents. Therefore, this history may be taken as fairly representative of the general development of the polyphase induction motor in the United States.

The Cost of a Kilowatt-Hour

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EVERY MANUFACTURER is to some extent interested in the subject of power, and in many industries the expense for power forms a considerable proportion of the total cost of production. Yet, until the last few years very little attention has been given to this subject. The latest, and probably the most aggressive agitation has been carried on by the central power stations, who are regularly making engineering studies of power conditions in various industries. The chief obstacle to the central station is that the average manufacturer is not a power engineer. For this reason power solicitors are at times compelled either to talk in generalities, or to use the everyday terms that are familiar to power men, but which may be so much "Greek" to the factory manager who has not made a study of the subject of power. Therefore a great deal of the solicitors sales energy is ineffective, because it is not fully comprehended. This article is presented to assist those who are not familiar with power problems to understand what elements are involved in the generation of electrical energy. The most frequently used terms are explained and illustrated and followed by a discussion of the effect of those items which are most important. Inasmuch as this article is written primarily for the non-technical man, elementary methods are used to bring out the desired points.

THE FINAL summing up of the results of operation of any power plant is the cost per "kilowatt-hour." This term is certainly brief and looks as if it might be easily understood. But when it is considered that there are more than a score of items involved in power plant operation, and that every one of these items is more or less variable, and finally that each item has its individual effect upon the cost of a kilowatt-hour, the term looks somewhat more formidable.

RELATION OF HORSE-POWER TO KILOWATT

The power capacity of steam engines and electric motors is nearly always expressed in horse-power, while the capacity of electrical generators is given in kilowatts. This is a source of confusion to the non-technical man, which can be eliminated by a few definitions.

The Unit of Work is the foot-pound, so called because it expresses the work required to raise one pound one foot. The horse-power is equal to 33 000 foot-pounds of work in one minute, introducing the element of time. To explain the significance of the term horse-power, assume an engine with a 10 inch piston which has a 12 inch stroke, and steam at 100 pounds pressure at the boiler. The steam from the boiler enters the cylinder at boiler pressure during only a small part of the stroke, the rest of the work after the steam valve closes being performed by the expansive property of the steam. The point at which the steam inlet valve closes is known as the cut-off and is determined by the valve mechanism and engine governor. From this point the steam expands and its pressure decreases as the piston moves forward and the volume of space occupied by the same weight of steam becomes greater. By the time the piston reaches the end of the stroke, the pressure has fallen to nearly the pressure of the external air, or atmospheric pressure. Therefore although the steam originally entered the cylinder at 100 pounds pressure, it has given up nearly all this pressure by doing work on the piston. The average pressure that has been at work on the piston is approximately half of the sum of the initial and final pressures; in this case say 50 pounds per square inch. This pressure is called mean effective pressure.* A 10 inch piston has an area of 78.54 square inches. Therefore the total force exerted on the piston is $78.54 \times 50 = 3927$ pounds. The stroke is 12 inches or one foot. Therefore if the piston is moved forward one stroke with a force of 3927 pounds, the work done is 3927 foot-pounds. Now if the engine is a double acting engine, that is, steam working on both sides of the piston, and if the speed is 100 revolutions per minute, then the piston makes 200 working strokes in one minute. Since the stroke is one foot, the piston would travel 200 feet in one minute; therefore, the work done is $3927 \times 200 = 785\,400$ foot-pounds per minute. Since one horse-power equals 33 000 foot pounds per minute, $\frac{785\,400}{33\,000} = 23.8$ horse-power would be developed in this engine. In one hour 23.8 horse-power-hours would be developed. In a rotating machine, such as a motor, the analysis is similar, in that it involves load (pounds), distance (feet measured from the axis of the pulley) and speed (revolutions per minute.)

In taking up the "kilowatt" we are dealing with an entirely new term, which at first seems to have no relation to anything connected with horse-power. A kilowatt is primarily an electrical term, while a horse-power is considered a mechanical term. The fundamental electrical unit of power is the "watt," one thousand of which make one kilowatt, from the prefix "kilo" denoting 1 000. A watt (in direct-current circuits) is the product of one volt and one ampere.

Let us imagine electricity as an invisible fluid flowing through a wire, as water flows in a pipe. In the latter case we speak of pressure and quantity,

*This is only a rough and ready rule. The exact mean effective pressure for the given cut-off should be determined from steam tables, for any exact calculations.

and we know that a certain amount of water flowing at a certain velocity and pressure has a certain power capacity, which is demonstrated, for example, in a water wheel. Now, in the flow of electricity, volts correspond to pressure and amperes correspond to quantity, and the power capacity of one ampere of current at one volt pressure is one watt. It has been determined experimentally that one watt is the power equivalent of $\frac{1}{746}$ of a horse-power. Therefore 1 000 watts or a kilowatt is $\frac{746}{1\,000}$ or 1.34 times a horse-power. Thus to convert kilowatts to horse-power multiply by 1.34, and to convert horse-power to kilowatts divide by 1.34. A kilowatt used for one hour constitutes a "kilowatt-hour."

COST OF PRODUCTION

Having a clear conception of a kilowatt-hour, let us see what factors are involved in its production and cost. In the first place we must picture a factory power plant consisting essentially of boilers, engines, generators and auxiliaries, such as boiler feed pumps, feed water heaters, etc. The cost of power may be separated into two main divisions, "fixed charges" and "operating charges," their sum making the "total operating expense." The total expense divided by the number of kilowatt-hours used, gives the cost of a kilowatt-hour. It is evident that it is necessary to have an accurate record both of the total operating expense, and of the number of kilowatt-hours. This latter can only be obtained by accurate measurement with suitable integrating or recording instruments.

FIXED CHARGES

The fixed charges, as the term implies, differ from the operating expenses such as coal, in that they do not vary according to the amount of power generated. Fixed charges are the result of the money invested in the power plant equipment and space occupied, and become effective from the moment the equipment is purchased. In order to buy this equipment, money had to be secured from some source or other. From whatever source obtained, money cannot be exchanged for permanent fixtures without incurring a loss equal to its ordinary earning power. This amount is termed interest. If the rate on borrowed money is six percent then this part of the fixed charges is taken at the same rate, the amount depending upon the value of the equipment in question.

Another similar charge is known as "fair profit." This is the difference between the percent of manufacturing profit and the interest rate. This charge is based upon the assumption that were the money invested in productive factory equipment, instead of being tied up in power-plant machinery, it would earn a greater profit than were it merely invested as a reserve fund or in bona fide securities. However this item is not commonly used in determining power costs.

The second important factor in fixed charges is "depreciation." Ordinarily, the life of power plant machinery is taken at twenty years, although this is somewhat too long, when efficiency is considered. We have seen how interest must be paid yearly on the equipment. What happens when it is no longer serviceable and needs to be replaced? Only one of two things can happen, either another loan must be transacted, thus doubling the interest, or a sufficient sum must be on hand to make the purchase. The manner in which this sum is accumulated forms the charge called depreciation. It is commonly based on the assumption that if a piece of machinery is good for twenty years, one-twentieth of its service is used up yearly, and hence an annual sum equal to one-twentieth of its original value is set aside as part of a sinking fund so that when the equipment is completely used up, funds will be available for new purchase. On ordinary power plant equipment this charge is usually taken at five percent of the valuation, but is subject to considerable variation according to existing conditions for any particular installation. A similar charge, but not so commonly used is "obsolescense." This is figured along the same lines as depreciation and provides for the contingency of more efficient equipment that might be used to replace existing equipment even before it has performed its maximum years of service.

The third important item usually included in the fixed charges covers insurance and taxes. These items require no explanation.

In summing up the fixed charges we have as the main items, interest, deprecation, insurance and taxes, obsolescense and fair profit. The fixed charges considered as a lump sum remain the same when taken as a yearly, monthly, or daily expense, but this method is neither satisfactory nor correct, because it prohibits an accurate determination of the cost of power per kilowatt-hour. Obviously, a greater number of kilowatt-hours makes the cost per unit less and vice versa. This is the thought that is expressed by the term "load factor."

Load Factor is a measure of the ratio of the actual power generated (or consumed) by an installation to the maximum that may be generated (or consumed.) Unfortunately, there are several interpretations of the term, so that wherever it is used, it becomes necessary to explain what particular meaning is intended. The differences are caused by a lack of uniformity in choosing the maximum power. It may be taken as the full-load rating of the apparatus times the total hours in a given period or times the actual operating hours in a given period. Also it may be considered as the maximum demand for power over any given period and multiplied by the total possible hours or by actual running hours in another period.

In order that the reader be not confused, we will stick to one idea, the one adopted by the National Electric Light Association, and several engineering societies, viz. the load factor is the actual power consumed per annum divided by the product of the installed rated capacity times 8 760 (hours in one year.)

Let us assume an engine-driven generator rated at 100 kilowatts. The rated capacity is the capacity at full load. This generator, if run at full load for one hour, would generate 100 kilowatt-hours. Operated at 50 percent load for two hours the power would remain the same. The load factor for the one hour would be 100 percent, but for the two hours would be only 50 percent, because at full load during these two hours the generator was capable of producing 200 kilowatt-hours. If the generator ran ten hours every day for 300 days per year at full load, the total power generated would be 100 kilowatts $\times$ 10 hours $\times$ 300 days $=$ 300 000 kilowatt-hours. But this machine may be considered capable of running 8760 hours in

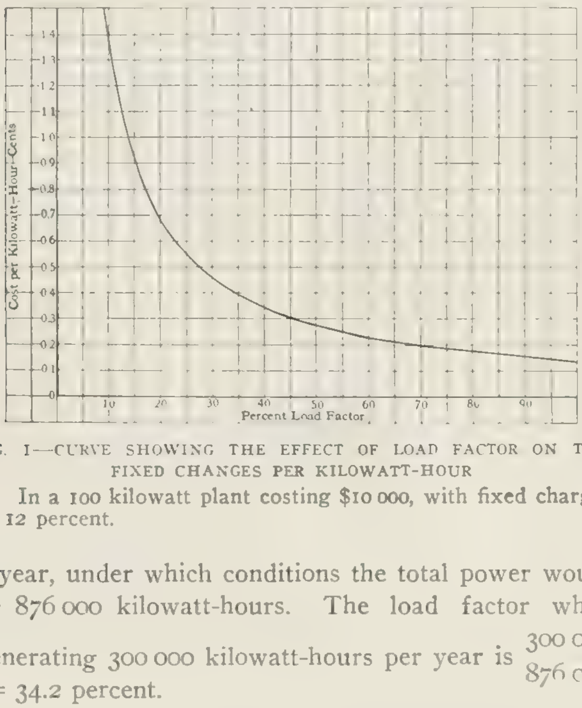

FIG. 1—CURVE SHOWING THE EFFECT OF LOAD FACTOR ON THE FIXED CHANGES PER KILOWATT-HOUR

In a 100 kilowatt plant costing $10 000, with fixed charges at 12 percent.

a year, under which conditions the total power would be 876 000 kilowatt-hours. The load factor when generating 300 000 kilowatt-hours per year is $\frac{300\,000}{876\,000}$ $=$ 34.2 percent.

Taking the same case and the same hours, but letting the average load be 50 percent, the power generated would be cut in half and likewise the load factor, which would then be 17.1 percent.

Every plant has its individual load factor. The industrial power plant does not change much from year to year. The plant of the power company has, in most cases, a gradually increasing load factor, due to additional customers and hence additional power.

The average load factors in various industries are pretty well known. A few of them are as follows:—

Boiler shops	10 to 20%	Foundries	5 to 15%
Shoe factories	15 to 25%	Knitting mills	about 25%
Breweries	about 45%	Machine shops	5 to 25%
Cement plants	60 to 90%	Clay products	15 to 20%
Coal mines	15 to 30%	Tanneries	10 to 20%
Cotton mills	20 to 30%	Textiles (general)	about 25%
Flour mills	20 to 25%	Woodworking	5 to 30%

These figures apply broadly to the industries as a class; certain cases will not lie within the given limits.

It is frequently necessary to arrive at a preliminary approximation of the total power that a plant would generate or a factory would consume. This can be done by figuring the maximum possible power from the rated capacity of the installation and multiplying by a load factor selected to suit the case. For instance, in certain machine shop, the conditions indicate that the existing load factor would be nearer to the high than to the low limit of the average figures given in the preceding list. Suppose we say it will be about 20 percent and suppose the shop power plant to have 100 kilowatts of rated generating capacity. The maximum power that could be generated in a year would be 100 $\times$ 8 760 $=$ 876 000 kilowatt-hours. Then with a load factor of 20 percent, the auctal power would be 20 percent of 876 000 or 175 200 kilowatt-hours.

Effect of Load Factor upon the Fixed Charges per Kilowatt-Hour—We have seen how money invested in a power plant incurs a permanent yearly expense. This expense is no respector of business conditions. Unlike the cost of labor, coal, etc., it does not decrease when the plant is running slack or cease when the plant is shut down. Therefore, the magnitude of the fixed charges can only be realized when based upon the net power. Again take the example of the 100 kilowatt power plant and let its original value be $10 000 and the fixed charges as follows:—Interest 5 percent, depreciation 5 percent, insurance and taxes 2 percent, total 12 percent. The annual fixed charges are 12 percent of $10 000 or $1200. If this plant has a load factor of 100 percent, the total power generated would be 876 000 kilowatt-hours, and the fixed charges per kilowatt-hour would be $\frac{\$1200}{876\,000}$ equals $0.00137, but if the load factor is only 25 percent, the fixed charges are four times as great, or over half a cent.

The effect of various load factors in the above example is illustrated in Fig. 1. The cost per kilowatt-hour increases rapidly for load factors less than 30 percent.

OPERATING CHARGES

Fuel.—The amount of fuel used per kilowatt-hour depends upon two things, viz., the amount of steam generated per pound of fuel fired and the amount of steam consumed per kilowatt-hour by the various power plant machines. Each of these items is dependent upon other variables. The steam product per pound of coal depends upon the heat value of the fuel, the manner in which it is fired, the quality and temperature of feed water, the general boiler conditions and the load. The steam consumed by prime movers per unit of delivered power

depends upon the efficiency of the machinery, the method of drive between engines and generators and driven machinery, upon the many details of transmission up to the point where power is used, and lastly upon the load conditions.

The steam generated per pound of coal is termed "evaporation." The results of many evaporation tests show figures varying anywhere from less than four pounds to over nine pounds of water per pound of coal. The greater number of tests, however, show results between six pounds and eight pounds. We may therefore assume seven pounds to represent the average conditions in industrial plants.

The steam consumption of pumps, engines, compressors, etc., depends wholly upon their individual design, engines and engine type pumps varying from about 20 pounds per indicated horse-power for high grade machines to around 60 pounds for the ordinary simple types subjected to the usual conditions found in the average industrial establishments. Direct-acting steam units, such as the ordinary type of horizontal pumps, which take steam throughout the entire stroke (that is do not utilize the expansive

TABLE I—CHARACTERISTIC PERFORMANCE OF SIMPLE SLIDE VALVE ENGINE

	Lbs. Steam per Ind. Hp-Hr.	Lbs. Coal per Ind. Hp-Hr.	Lbs. Coal per Delivered Hp-Hr.	Lbs. Coal per Delivered Kw-Hr.
Full load............	30	4.3	6.34	8.5
One-half load	40	5.7	8.41	11.2
One-quarter load.	50	7.1	10.47	14.0

power of the steam) will take from 100 to 250 pounds of steam per horse-power-hour. Compressors vary about like engines, according to the type and class of service.

Let us take another example of an engine driving a 100 kilowatt generator. Let the generator have an average efficiency of 85 percent and the engine 80 percent for all loads. These are mechanical efficiencies and express the relation of the power output to the power input. The input to a generator having a 100 kw output, and operating at 85 percent efficiency would be $\frac{100}{0.85} = 118$ kw. This equals the output of the engine, which at 80 percent efficiency would require an input of $\frac{118}{0.80}$ 147.5 kw or 198 indicated horse-power. This would be the power at the cylinder of the engine as determined by a steam engine indicator. The relation of the engine input to the generator output is $\frac{147.5}{100} = 1.475$. If the engine is of the simple, slide valve type its steam consumption per indicated horse-power will be approximately as follows:—

Full load, 200 hp = 30 pounds of steam.

One-half load, 100 hp = 40 pounds of steam.

One-quarter load, 50 hp = 50 pounds of steam.

Also assume that the boiler plant is generating seven pounds of steam per pound of coal. Then, for instance, at one-quarter load the coal per horse-power would be the steam per horse-power (50 pounds) divided by the rate of evaporation (7 pounds), viz. $\frac{50}{7}$ = 7.1 pounds. At half load the coal rate would be 5.7 pounds and at full load 4.3 pounds per indicated horse-power. If these figures are made to express coal per delivered horse-power we must multiply by 1.475, and if we wish coal per delivered kilowatt we must again multiply by 1.34 as shown in Table I. From the second and last columns of figures in this table, the manufacturer who contemplates purchasing an engine will obtain information which will be of valuable assistance in his negotiations.

It is important to note that these figures do not cover the coal required for banking boilers and for the steam used by feed pump and other auxiliaries. It is a great mistake to figure the steam per delivered unit of power without considering these items. Banking alone requires from 5 to 20 percent additional coal over that actually used during working hours. Auxiliaries take from 1 to 10 percent, and frequently more, of steam, in addition to the actual steam used in the engines, compressors, etc. Therefore in an industrial plant where it is necessary to bank boilers for about 14 hours per day, there would be quite an increase over the net coal and steam per kilowatt-hour. However, since these items are open to such a wide range of variation, it would be useless to attempt to compile any date to apply in general to all cases.

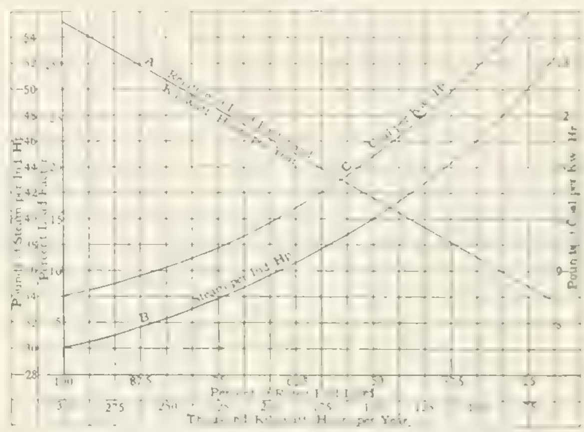

FIG. 2—LOAD CHARACTERISTIC OF A 100 KILOWATT PLANT
Operating 3 000 hours per year.

In order to give more complete information regarding the variation of steam and coal per unit of power, attention is called to Figs. 2 and 3. The curves on Fig. 2, are based on the assumed 100 kilowatt plant operating normally 3 000 hours per year, with the assumed efficiencies, steam consumption, and steam generated per pound of coal. Curve *A*, shows the relation between load factor and kilowatt-hours generated per year. Curve *B* shows the pounds of steam per indicated horse-power at the engine at various operating loads, the loads being simply an-

other expression of the power output. Curve *C* shows the coal consumed per kilowatt hour corresponding to the conditions of steam per indicated horse-power. This curve involves the efficiencies of the machinery and coal rate, already explained.

Fig. 3 shows the cost of coal only per kilowatt-hour with coal at different prices per ton, and based

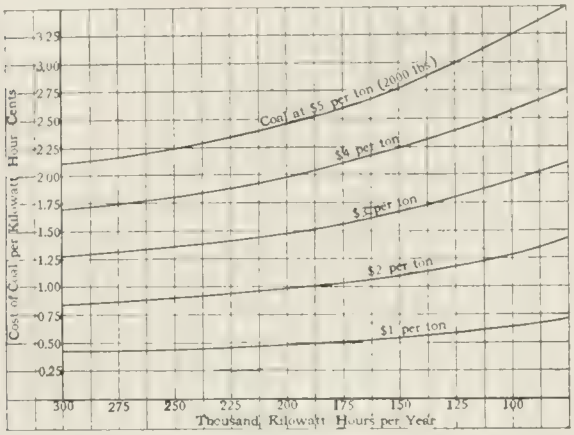

FIG. 3—COST OF COAL PER KW-HR
At various loads on a 100 kilowatt plant.

on the coal consumed per kilowatt-hour as given in curve *C* of Fig. 2.

Labor—Next to fuel, the labor is the highest expense in operating costs. Inasmuch as it is a constant expense it affects the kilowatt-hour cost in the same manner as the fixed charges. A curve to show the effect of labor cost upon the kilowatt-hour cost would be similar to Fig. 1, the values being determined by the proper scale of ordinates.

Miscellaneous Expense—This item includes feed water, repairs, oil, waste, packing, etc. These expenses vary with the size, type and general care of the plant.

USE OF LIVE STEAM

In a manufacturing plant, having several departments which not only require power, but also use steam for various processes requiring heat, in addition to the general heating required in cold weather for buildings, the cost of generating live steam must be separated from the cost of power. It is obvious that to get the correct cost of power, the entire expense of the power plant, especially the boiler plant, must be analyzed and proportioned accurately. This is particularly important in negotiations between central stations and industrial power users. The solution of these points must come from actual test.

After having the results of the steam tests, it is necessary to compute first the total steam per year, and then the steam used for various purposes, expressing each quantity as a percentage of the total. Most important is the percentage of steam chargeable to power. This does not always mean the amount used directly by the engines. In fact it can only be computed on this basis when the exhaust steam is not utilized. For example, the writer was recently engaged in making a power investigation in one of the most prominent resort hotels in the country, to determine whether it would be advantageous to the hotel company to discontinue the use of their antiquated plant and purchase their required electrical power from the local power company. The situation had reached a point where it was necessary to do this or buy new engines and generators. A complete test of the steam conditions, briefly stated, gave results as shown in Table II. Referring to item 7, note that this live steam is additional to the exhaust from the engines. Now, if the engines are removed, sufficient live steam will have to be used for heating to meet the building requirements. A test and general computation determined that the heating for an average year would be covered by 13 500 000 pounds of live steam. Incidentally this figure is equivalent to 465 pounds of steam per season per square foot of radiating surface. However, 3 460 000 pounds of live steam are already used for heating buildings, as is given in item 7. Therefore the additional live steam that would be used if no exhaust were available, would be 13 500 000 minus 3 460 000 = 10 040 000 pounds. Therefore the exhaust from the engine room is worth this amount of live steam. Item 2 shows that 27 928 000 pounds of live steam were used per year by the engines. This amount must be credited with 10 040 000 pounds of live steam as exhaust equivalent, thus leaving 17,888 000 pounds of steam actually chargeable to electric power generation. The steam plant costs were figured separately with a resultant cost of 25¢ per 1 000 pounds of steam.

Hotels and public buildings in general, are conceded to be the most difficult problems for the central stations, particularly where the central station does not sell steam. This instance however, developed into a very good proposition both for the customer and the power company. It is interesting to know that the hotel company is able to make a saving by buying power at over two cents per kilowatt-hour and, regardless of a material saving in general operating expense, they avoided the expenditure of over $10 000 for new equipment.

TABLE II—RESULTS OF TESTS ON A HOTEL PLANT

Item	Pounds steam	Percent
1—Total per year	73 650 000	100
2—Used by engine driving generator	27 928 000	37.8
3—Miscellaneous pumps	20 714 000	28.2
4—Used by kitchen	6 570 000	8.92
5—Ammonia compressor	5 256 000	7.13
6—Used by laundry	4 000 000	5.42
7—Live steam for heating	3 460 000	4.70
8—Bath & massage treatment dept.	3 093 000	4.23
9—Elevator pumps	2 628 000	3.60

Shop Testing of Electrical Apparatus—XIX

THE CIRCLE DIAGRAM FOR SINGLE-PHASE TRANSFORMERS

CHAS. FORTESCUE

BY MEANS of the circle diagram the loci of the ends of the vectors representing secondary terminal voltages and currents of a transformer may be located at all power-factors and for all loads. The amounts of and vector relations between the primary and secondary e.m.f's and currents under any conditions of load and power-factor may be determined, and the regulation may be obtained graphically.

When the primary e.m.f. is fixed, the end of the vector which represents the secondary e.m.f. for a given load current will have as a locus, a circle with its center at the end of the vector representing the secondary open circuit voltage and a radius equal to the short-circuit impedance voltage for the given load current. To draw the diagram, lay off $OA = E_1$, Fig. 1 representing the primary impressed e.m.f. reversed in time phase, and divided by the ratio of transformation, and $OB = E_2$, representing the secondary open-circuit e.m.f. in its proper phase relation. The radius of the circle with B as its center represents the secondary short-circuit impedance of the transformer on the same scale as OB represents the secondary open-circuit e.m.f. The construction for obtaining the loci of the secondary terminal voltage for any load is as follows:—

Bisect OB at O_3 and draw $O_2\,O_4$, at right angles. The locus of the ends of the vectors representing voltage at all loads having a given power-factor is a circle passing through B with its center at some point on the line $O_2\,O_4$, the position of the point and the corresponding locus circle varying with the value of the power-factor. The center O_1 for unity power-factor is obtained by making $O_1\,O_3$ equal to $O_3\,B$ multiplied by the ratio of the secondary short-circuit resistance to the secondary short-circuit reactance; or this may be done graphically by laying off BE along OB and to the same scale as OB to represent the reactance drop, and ED at right angles to OB to represent the resistance drop. BD, the vectorial resultant of these two, is by definition the total impedance drop. Hence D must fall on the locus circle and accordingly O_1B is a continuation of the line BD. The centers $O_2\,O_4$ etc., for loads of other power-factors are obtained by making cos a_2 cos a_4 etc., equal to the respective power-factors, making the angle lag behind or lead BO_1 according as the power-factor is lagging or leading. Or these angles may be laid off graphically by constructing a circle tangent to $O_2\,O_3\,O_4$ at O_3 with center at B, and laying off along BO_1, a distance BL whose ratio to the radius of the circle BK is equal to the power-factor expressed decimally. The perpendicular erected at L then represents the chord of the double angle of lag and lead desired. Thus when $BL = 90$ percent of BK, O_3 is the center for 90 percent power-factor leading, and O_2 for 90 percent power-factor lagging. The loci are then obtained by describing circles passing through B with O_1, O_2, O_3, etc., as centers.

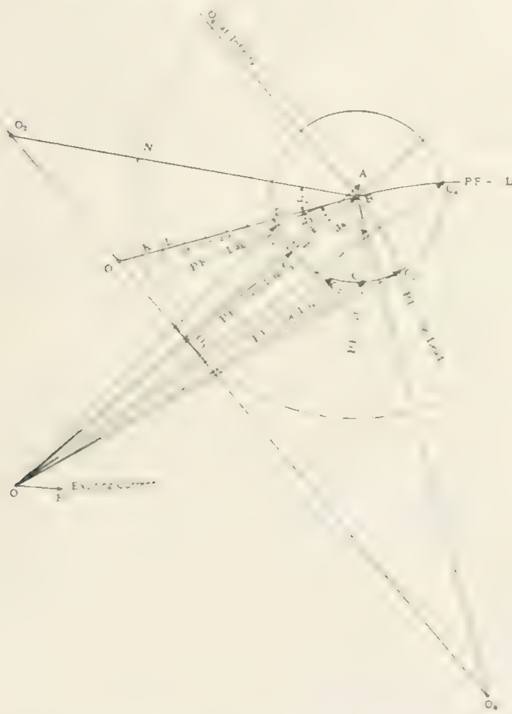

FIG. 1—DIAGRAM OF VOLTAGE VECTORS

FIG. 2—DIAGRAM OF CURRENT VECTORS

The loci of the voltage vectors for different load currents are concentric circles having B as a center and radii proportional to the respective short-circuit impedance drops at these loads. The vector of secondary terminal e.m.f. for any given value of load current and power-factor of load is, therefore, the line drawn from O to the point of intersection of the load-current circle and the power-factor circle. Thus, the secondary terminal e.m.f. with full load secondary current and 90 percent leading power-factor is represented in time phase and magnitude by the vector drawn from O to the point C_3, where the circle representing 90 percent leading power-factor intersects the full-load impedance drop circle.

To obtain the loci of the ends of the current vectors, describe a circle with center at O of radius to represent the effective full-load secondary current to any suitable scale. These curves can be drawn on the same diagram as the voltage vectors, but to avoid confusion the method of obtaining them is shown in Fig. 2. With the same center O, draw another circle of radius equal to that of the first circle multiplied by the ratio of one-half the secondary open circuit voltage to the secondary full-load short-circuit impedance volts. Take OB equal in time phase and magnitude to the secondary open circuit voltage. Draw $O\ M_1$ at right angles to OB and make the angle $M_1\ O\ M_3$ such that its cosine is equal to the short-circuit reactance divided by the short-circuit impedance. Draw a line $M_2\ M_1\ M_3$ tangent to the second circle at the point M_3. This line is the locus of the centers of the circles passing through O which are the loci of the secondary load current vectors for different power-factors. M_1 is the center for the circle passing through O which is the locus for the current vectors for all loads of unity power-factor. Other centers are found by laying off the phase angles in the same way as for the secondary voltage loci. The loci for different values of secondary load currents are circles with O as a center and radii proportional to the effective values of the load currents. The current vector for any given value of load current and power-factor of load is, therefore, the line drawn from O to the point of intersection of the load current circle and the power-factor circle. The approximate primary current is then obtained by combining this vector with the vector OF, Fig. 1, representing the open circuit current. The error in taking the open circuit exciting current vector is very small and is about the same at all loads.

The Risk Involved in Directing a Stream of Water onto a High Tension Line

FOREWORD—The following information on this subject was secured in connection with our Question Box service. The experiments showing the actual voltage to ground obtained at the nozzle of a fire hose were made under the supervision of the office of the General Superintendent of Motive Power of the Pennsylvania Railroad Company at Altoona, Pa., and are presented by permission of the Pennsylvania Railroad. The tests showing the resistance to ground were made by Messrs. Allan Bond and O. G. Galland at the Ohio State University under the direction of Professor F. C. Caldwell; the results of these tests were originally published in the Sibley Journal of Engineering.—*(Ed.)*

EXPERIMENTS WITH FIRE STREAMS AT ALTOONA

IN ORDER to determine definitely what hazards, if any, exist for firemen when they are compelled, in line of duty, to play water from fire streams on line wires at various potentials, arrangements were made so that circuits of 525, 2 300 and 4 600 volts, respectively, were available. The 525 volt line was a direct-current trolley wire connected to the trolley of the Altoona & Logan Valley Electric Railway Company. The 2 300 and 4 600 volt lines were fed from alternating-current generators at the Altoona Car Shops. One side of each of these circuits was thoroughly grounded and the fire stream was played on the other side, which was suspended in the air and thoroughly insulated. A suitable voltmeter was connected between the nozzle and ground to enable the difference of potential between the nozzle and ground to be noted in each case.

The results given in Table I were obtained in tests made the day previous to the general demonstration. These results show that the nozzle may be handled without discomfort up to a point between three and four feet from the wire when those handling the nozzle are standing on the ground. It may be carried much nearer without harm but would probably cause discomfort. If those holding the nozzle were standing on a wooden ladder or were otherwise insulated from the ground, it would be quite safe to bring the nozzle to within a few inches of the wire. In each of the tests indicated in Table I, at 2 050 and 4 100 volts, no measurable deflection could be obtained on the voltmeter, but upon touching the nozzle with the hand, when standing on the ground, a slight effect due to the static electricity was noted.

In the demonstration held on the succeeding day, results were obtained which agree with those shown in Table II. In each case the nozzle was sufficiently near the wire to cause a solid stream to play on the latter. Just how far the results of a fire hose test with salt

water will differ from the above, which were made with fresh water, cannot be said at the present time.

Experiments were also made with streams from hand chemical extinguishers, and it was found that when a solid stream is played on a high potential wire it *becomes a source of danger* to the one holding the extinguisher. For instance, the nozzle of an extinguisher was held at a distance of nine inches from a grounded 2 050 volt alternating current line. The difference of potential between the nozzle and ground was 1 500 volts when the extinguisher was insulated from the ground.

TABLE I. VOLTAGE TO GROUND FROM A FIVE EIGHTS INCH NOZZLE.

Voltage on Wire	Distance from Nozzle to Wire	Volts between Nozzle and Gronnd
525	7 ft. 5 in.	20
525	4 ft. 9 in.	38
525	3 ft, 7½ in.	60
525	2 ft. 2 in.	70
525	0 ft. 7½ in.	210
2050	6 ft. 6½ in.	Static
2050	3 ft. 5½ in.	Static
4100	6 ft. 6½ in.	Static
4100	3 ft. 5½ in.	Static

TABLE II.—RESULTS OF DEMONSTRATION AT ALTOONA.

Size Nozzle	Voltage on Wire	Distance from Nozzle to Wire Feet	Volts between Nozzle and Ground
⅝ in.	525	3	Slight indications of static electricity to the hand
1 in.	2300	8	Slight indications of static electricity to the hand
1 in.	4600	10	Slight indications of static electricity to the hand

THE RESISTANCE OF A STREAM OF WATER

These tests were made to represent actual conditions as nearly as possible by using regular fire hose and nozzles, the latter of the sizes most used, one and one-eighth and one and one-half inches in diameter, the dimensions of the nozzles being given in Fig. 1. The water used was from the condensing tank of the University power plant. It had been softened by the use of soda and lime and probably would have shown a somewhat lower resistivity than average city water. This, however, as will appear later, would not affect the more important deductions made herein.

The investigation took the form of measurements of the resistance of the stream of water between the hose nozzle which was grounded and a 12 foot piece of No. 6 copper wire, strung horizontally ten feet above the ground. The voltage was obtained from one terminal of a 250 000 volt, 50 kilowatt transformer. The middle point of the high tension winding was connected through a low reading ammeter to earth; one terminal was connected to the wire while the other terminal was open. The required value of the voltage was obtained by the proper excitation of the primary and its value determined by a voltmeter on the primary and the transformation ratio of the transformer. Variation of the frequency between 60 and 45 cycles with 20 000 volts impressed upon a six foot stream of water showed that there was no appreciable reactance. The resistance was thus calculated from the current and applied voltage.

The voltage, water pressure and length of stream between the nozzle and the wire were varied and the effect of each upon the resistance was studied. Variation of voltage produced no well defined effect upon the resistance within a range between 5 000 and 30 000 volts. In this test water pressures from 30 to 70 pounds were used and a stream length from 6 to 15 feet.

Increase of water pressure gave increased resistance. This was slight for six and ten foot stream lengths, but quite marked for fifteen feet. It appears that with the higher pressures the stream is less solid, especially at a greater distance from the nozzle.

The really striking and interesting results obtained from the tests, however, came with the variation of length of stream. The results with the one and one-eighth inch nozzle are shown in Figs 2 and 3 for 5 000 and 30 000 volts, respectively, and for different pressures. With 20 000 volts the curves are practically the same as those shown for 30 000 volts. Fig. 4 gives similar curves for the one and one-half inch nozzle.

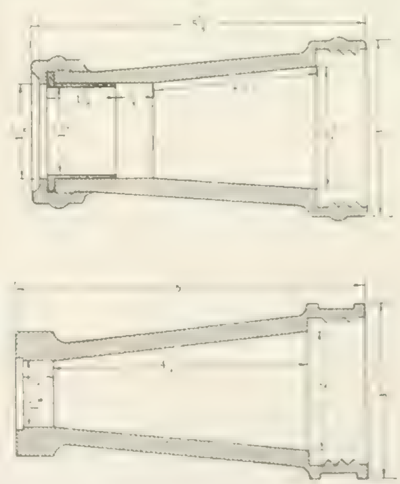

FIG. 1—[illegible]
Showing dimensions and types of orifices.

In all these curves the resistance increases gradually up to a critical length which for the one and one-eighth inch nozzle is about 17 feet, and for the one and one-half inch nozzle 20 feet. Beyond this point the resistance rises suddenly and approaches rapidly to infinity. This critical length is nearly independent of

the pressure used, though becoming slightly lower for higher pressures. Observation of the stream of water makes the cause of this critical length clear. It is the

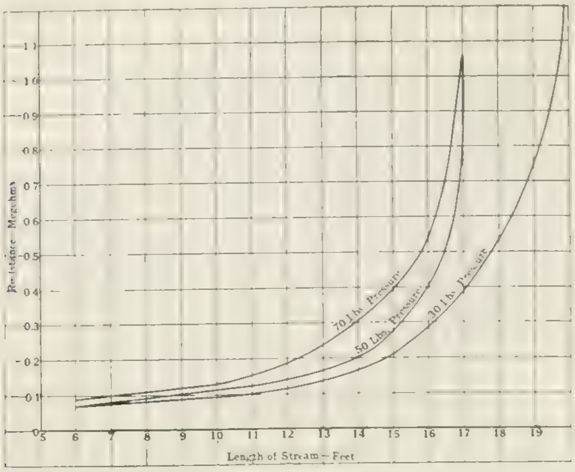

FIG. 2—CURVES OF RESISTANCE
With varying stream lengths from a one and one-eighth inch nozzle, directed onto a 5 000 volt line.

point where the stream ceases to be continuous and breaks up into a mass of separate water drops.

As to the bearing of these results, it may be noted that a current of 0.02 amperes is quite painful to most persons and that 0.05 amperes is at or beyond the limit of endurance. While the minimum fatal current is very uncertain, it is probable that it would very seldom be less than 0.1 ampere and usually much more. If a stream length of fifteen feet and 50 000 volts are taken as an example, the curves show that for a one and one-eighth inch nozzle a resistance of about 20 000 ohms would be obtained and hence a current of about

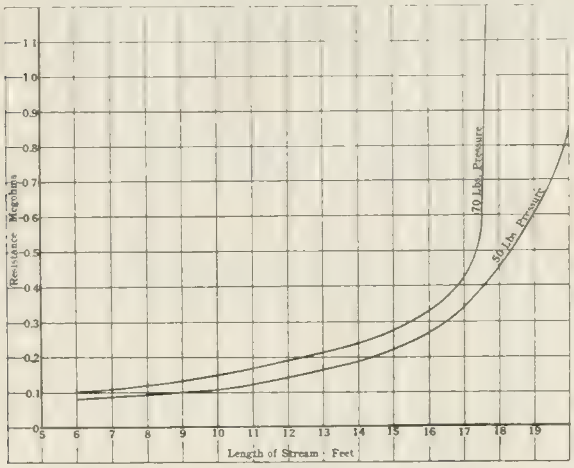

FIG. 3—CURVES OF RESISTANCE
With varying stream length from a one and one-eighth inch nozzle, with stream directed onto a 30 000 volt line.

0.25 amperes. Such a current would certainly give a severe shock and in some cases would be dangerous. If, however, a stream length of 20 feet is assumed for a one and one-eighth inch nozzle, or 25 feet for a one and one-half inch nozzle, the resistance would be 800 000 ohms or more, which for 50 000 volts would give but 0.06 amperes or less which, while painful, would practically never be dangerous to life. In these calculations the resistance of the body, being only a few thousand ohms, has been neglected.

Since high tension circuits should always, when near buildings, be carried on poles that would bring the lines much more than 25 feet from the ground, it would seem that little fear of injury to firemen from this source need be entertained so long as the poles are of proper height and the fireman is working from the ground. If, however, he is working from a metal ladder, or is using a tower which would bring the noz-

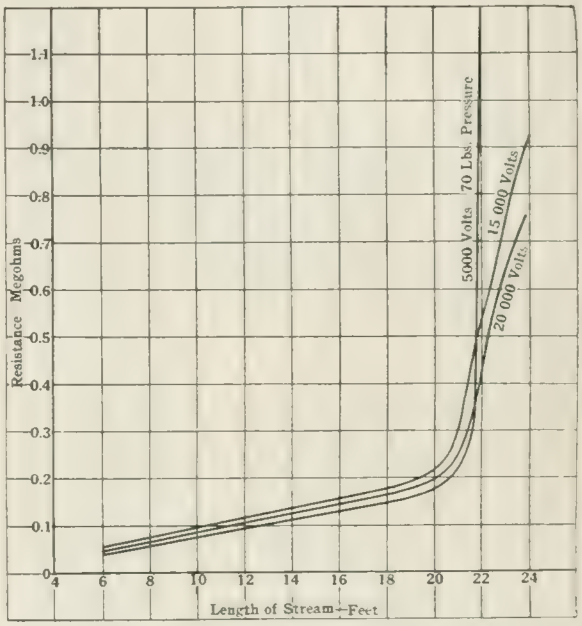

FIG. 4—RESISTANCE CURVES
For various voltages with a one and one-half inch nozzle, and 70 pounds water pressure.

zle into close proximity to the wire, a dangerous shock might be received through the stream.

It may be asked whether the fact that the nozzle is grounded through the stream of water in the hose would not keep its voltage so near that of the earth that even with the short stream length there would be no danger. With this point in mind the resistance of the path from nozzle to ground through the water in the hose was investigated when the latter was thoroughly insulated from the ground and found to be about 150 000 ohms per hundred feet, from which it would appear that such a ground connection could not be depended upon to shunt much of the current around the man holding the nozzle.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1076—Motor on Over-Voltage—(a) Would you advise running a 150 horse-power, three-phase, 60 cycle, 440 volt, motor on a 550 to 600 volt circuit? (b) Will the same starting transformer do? (c) Is there any advantage in running a 550 volt motor on 600 volts, outside of overcoming line losses? (d) Are the manufacturers specifications the the same for a 440 volt motor as for a 550 volt motor with the exceptions to the iron? M. L. C. (R. I.)

A 440 volt motor should not be run on 550 to 600 volts. The iron loss would be materially increased in any normal design, and the motor would in all probability overheat to a dangerous temperature at no load, running idle. Even if the motor did not become oversaturated the magnetizing current would be greatly increased and a very poor power-factor would result. Reliable manufacturers guarantee motors to operate on ten percent more than normal voltage, and that is a safe maximum to assume. (b) No. (c) The voltage at the motor terminals is what counts, and it is the most desirable condition always to have this as near as possible to the maker's rating. It is customary to install a 600 volt generator to handle 550 volt motors in order that there will actually be 550 volts at the motor terminals. (d) There is ordinarily no change in the iron between a 440 and a 550 volt motor having all other characteristics the same. The change is in the stationary coils. The 550 volt motor has approximately five-fourths as many turns in series in its coils, and the conductor is as nearly four-fifths the section as it can conveniently be made. A. M. D.

1077—Twenty-Five Cycle Lighting—Is it good practice to use twenty-five cycle systems for incandescent lightin? Are there many such installations in service? E. R. (IOWA)

On account of the flicker that occurs when low voltage incandescent lamps are used on 25 cycle circuits, lighting companies have generally standardized on 60 cycle power for this load. Whether or not it is good practice to use a 25 cycle system for incandescent lamps depends almost entirely on local conditions. Considered entirely from the quality of the light from 25 cycle lamps, there is little argument in favor of a 25 cycle system when comparied to a 60 cycle system. Where it is necessary to furnish a considerable direct-current load, such as a railway, variable speed direct-current motors, etc., and convert this direct-current power from alternating-current, the 25 cycle system may possess a little advantage. Synchronous converters for use on 60 cycles give about as good performance as on 25 cycles, and of late there seems to be a determined effort to eliminate as far as possible the use of 25 cycle systems and confine the demands to 60 cycles. There are several large cities in this country that use 25 cycle system for commercial incandescent lighting. The city of Buffalo and surrounding territory, including Niagara Falls, uses 25 cycles for incandescent lighting. Also, the Canadian cities of Toronto, Hamilton and others taking power from the Hydro-Electric Company's lines use the 25 cycle system. Whether or not the flicker from the lamp is serious depends largely upon the size of lamps used and the nature of the installation. A given 25 cycle lamp may not have a perceptible flicker when observed directly, but the flicker effect may become very objectionable if the lamp is suspended in close proximity to a white wall or other reflecting surface. C. E. S.

1078—Reversal of Elevator Motor—The connections of a 10 horse-power, 150 volt, 60 amperes, 800 r.p.m. com-

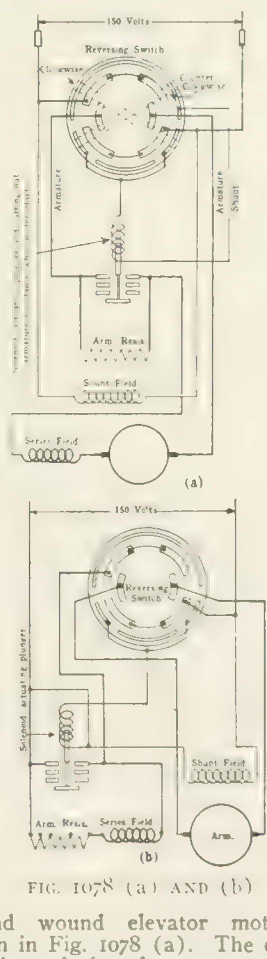

FIG. 1078 (a) AND (b)

pound wound elevator motor are given in Fig. 1078 (a). The counterweights of the elevator are so balanced that when the brake is released, the elevator coasts up if given a start, so that on going up no trouble is experienced, but when started down, as soon as the armature resistance is cut out, the motor reverses and takes the elevator up against the stops. The main line fuse is blown when this occurs. This condition exists only after the motor has been run long enough to heat the shunt coils quite considerably. With full-load on the motor, the shunt field current was found to be 8.7 amperes. Will you please explain what causes this motor to reverse without the operator touching the reverse switch after he has started the elevator down? N. H. (OHIO)

The series field is tied permanently to the armature and is being reversed with the armature. This is unquestionably the cause of the trouble, and if the questioner would put his elevator in the middle of the shaft he would probably find that the car would run up and then down and then up and down indefinitely. The cause of this is owing to the fact that the torque of the motor with the two fields bucking is not sufficient to run the elevator and the car slows down, taking more current from the line until the series field reverses the polarity of the field poles of the motor, thus reversing the motor. If allowed to run long enough in this direction the series field would gradually weaken until the shunt field again becomes the stronger magnetizing force, when the motor would again reverse and the action would be repeated. It is always unsafe to run elevator motors with the series field in circuit, except in the starting positions, for with an overhauling load, such as is found when lowering a heavy weight, the tendency is to weaken the field of the motor and make the machine run away. We believe the diagram in Fig. 1078 (b) will give the best connections, using the controller as it now stands. In this diagram the series field has been connected in place of the last step of resistance. The last step of the present resistance can probably be left in circuit and the conection simply transferred from this step of the resistance cutout device to the other side of the series field, thus cutting out the last step of resistance and the series field together. H. L. B.

1079—Manufacture of Carbon Filament—Please describe the process for the manufacture of the carbon filament inside of an ordinary incandescent lamp. S. B. M. (VIRGINIA)

Carbon filaments are to-day made entirely by the so-called squirting process. The material is a fine grade of cotton which is dissolved usually by a strong hot solution of zinc chloride and hydrochloric acid. At first a jelly-like substance is produced, but finally the cotton is completely absorbed and the resulting liquid, called cellulose, is a heavy syrup.

While still hot the solution is filtered to remove impurities. After cooling it is forced through a platinum die by air pressure, emerging as a continuous thread into a jar of wood alcohol which solidifies the thread. The thread is coiled in the bottom of the jar from which it is later removed and washed in water, and is then wound on drums about four feet in diameter and dried. The dry cellulose thread is then wrapped on carbon forms and embedded in charcoal or graphite and is then heated to about 3 000 degrees C. This converts the cellulose into carbon producing the carbonized filament. After carbonization, the filaments are treated or flashed. This process is as follows: The filaments are cut the proper lengths and then clamped in suitable clamps in a receptacle from which the air has been removed, and a carboniferous gas, usually of gasoline, substituted. Sufficient current is allowed to flow through the filament to cause it to glow. This heat is sufficient to cause carbon to be deposited on the filament in a form similar to graphite. This greatly reduces the resistance of the filament and also increases the mechanical strength. When the proper resistance is obtained, the current is automatically cut off. This process also results in a more uniform filament throughout its length, as the thin places become hotter and, therefore, receive a greater deposit of carbon, making the filament very uniform. After the filament is thus made it is mounted in the glass stem, the leading in wires are connected and then the stem is sealed into the bulb. after which the lamp is exhausted and then the bulb is sealed. Then when bases have been put on the lamps, they are read for use. S. A. F.

1080—Single-Phase from Three-Phase—Referring to question No. 1010 may I ask, (a)—Whether there is any particular reason for a *Y* connection of the primary. Will a delta connection with 2 200 volts primary do equally as well? (b)—Would an open delta or *V* connection with one transformer conected to give 440 volts, and the other 220 volts, the latter bucking the former, prove successful? In either case would it not be necessary to have sufficient transformer capacity in each phase to carry the load independently, that is to say, with a 25 k.v.a. welder, would it not require three 25 k.v.a. transformers if connected as per No. 1010?

F. J. F. (ILLINOIS)

(a)—It makes no particular difference whether the primary is delta or star connected. (b)—If, by "bucking the former," you mean that one of the transformers shall be reversed in polarity with respect to the ordinary *V* connection, there is no necessity for having two different voltages, unless an odd voltage is desired, as better results will be secured if both transformers are connected for 440 volts. As stated in No. 1010 this connection gives exceedingly poor power-factor relations on the primary and is not in general to be recommended. With three transformers the capacity of each transformer would have to be one-half of the capacity of a single transformer taking the power from one phase, so that 50 percent excess transformer capacity would be required, and the heating of the generator would be much greater when supplying a given k.v.a. output with this connection than when supplying the same k.v.a. output from one phase. With a *V* connection one leg of which is reversed, the capacity of each transformer would have to be 58 percent of that of a transformer carrying the same load single-phase, but in this case not even the primary currents will be balanced, although the third phase wire will carry some current. In general, from an engineering standpoint, this connection cannot be recommended, although there are undoubtedly some occasions when it may be advisable. C. R. R.

1081—Varying Diameter of Choke Coils—We find that the available space for a number of air choke coils for use with electrolytic lightning arresters is not sufficient, and are considering reducing the diameter from approximately eight inches, re-winding to a smaller diameter with the same number of turns, discarding part of the material. What effect will this have upon the function of the coils?

G. M. (ALBERTA)

The inductance of a choke coil of this type is reduced with the square of the diameter. Hence, reducing the coil to approximately half its original diameter with the same number of turns will give approximately one-fourth the original inductance. By winding the same amount of wire into a coil of half the original diameter, approximately twice the original number of turns will be produced which, with the same space between turns, will give a coil twice as long. The inductance increases with the length of the coil, although not in direct proportion. However, such a coil having half the original diameter and twice the original length will give almost half the original inductance. As the function of the choke coil is to protect electrical apparatus, it follows that a coil of only half the original inductance will give only one-half as much protection. It may be, however, that this is ample for your purpose. G. C. D.

1082—Power-Factor of Water Rheostat—What power-factor is produced by a water rheostat when used as a load on a 2 300 volt, 60-cycle alternator? R. R. C. (PENNA.)

The power-factor of a water rheostat, measured at its terminals, is approximately 100 percent, as there is no inductance in water. However, in many cases where a water rheostat is used, there is from 100 to 300 feet of cable per phase, running across iron bedplates or supported on or near iron posts or girders, which introduces more or less inductance, and the power-factor measured at the machine terminals may vary from 98 percent to nearly 100 percent, depending on the above named conditions. With certain solutions and metal plates there will be an anode polarization and condenser action between the anode and solution. At 2 300 volts this effect is small, but in low voltage rheostats this effect may cause a power-factor as low as 30 percent leading. This extreme condition would exist with aluminum plates and a solution containing a salt or acid which forms an insoluble compound with aluminum. With the iron plates ordinarily used in water rheostats this effect is usually negligible.

N. E. W. & L. W. C.

1083—Synchronous Motor Trouble—We have four 2 200 volt, three-phase, 30 pole, self-starting motors, driving pulp grinders. One of these motors will only carry two mills, and takes slightly over full-load curent, while the others are driving four mills. On examining the revolving field I found that instead of having copper bars on the squirrel-cage starting winding which is inserted through the pole face, a white metal composition was used. On starting this particular machine the inrush is very small as compared with the other machines. I then decided to inter-change the fields with one of the machines which had been laid up for repairs; then this motor carried its proper load without trouble. The rotor with the white metal composition bars was put in the other machine and acted as before, taking excessive currents when four mills were put on. I went over the air-gap and made sure the poles were centered in the stator, tried all kinds of field excitation, but could not get it to operate as the other three machines. I fail to see where this starting winding has anything to do with this excessive taking of current. I also made a resistance test of the copper and white metal windings and the readings were: copper, 0.0078, white metal, 0.0077. Would you please advise me as to where the the trouble of this machine is likely to be? W. A. M. (NEW JERSEY)

The white metal mentioned is probably Muntz metal or a similar high resistance material. This is indicated by the fact that the machine with the white metal damper has a small starting current. The resistance readings, however, on the two materials indicate practically the same resistance, which is not consistent with the other fact mentioned. We can only account for the motor with the white metal damper being able to drive only two grinders, while the other motors (identical except as to damper winding) drive four grinders, by the assumption that the motor with the higher resistance damper winding hunts itself partially or completely out of step. If this motor does hunt, the fact would be evident by the pulsation in the armature current. The starting winding can have no effect on the current taken by the motor or cannot affect the pull-out torque of the motor if the motor is actually operating synchronously. As indicated above, it can only have the observed effect in case hunting exists. F. D. N.

1084—Drying Generators—Kindly inform me as to the best method of drying out 440 volt, three-phase, 60 cycle alternating-current generators and motors. The generators are of the revolving field type and the motors are squirrel-cage. Would it be feasible to dry out the stator coils on the motor at the same time as the generator, if running the generator on short-circuit or wattless current. Would it be necessary to have some resistance in the motor circuit if the rotor was removed from the stator?

A. W. (INDIANA)

The best method for drying out machines is often determined by the facilities available for doing this work. Usually it should be done with the armature short-circuited and with the field current so adjusted as to raise the temperature to about 85 degrees C. The current is then adjusted by means of the field rheostat to maintain this temperature until the coils become thoroughly dry. During this procedure the temperature should not be allowed to drop to that of the surrounding atmosphere, as the moisture would then be

condensed on the coils and the machine brought to the same condition as at the start. There is always danger of overheating the windings of a machine when drying them with current, as the inner parts, which cannot quickly dissipate the heat generated in them and which cannot be examined, may get dangerously hot while the more exposed and more easily cooled portions are still at a comparatively moderate temperature. The temperature of the hottest part accessible should always be observed while the machine is being dried out in this way and it should not be allowed to exceed 80 degrees C, total temperature. It may require several hours, or even days, to dry out the machine thoroughly, especially if of large capacity, as large field coils dry very slowly. Insulation is more easily injured by overheating when damp than when dry. During the drying out run, readings of the insulation resistance should be taken at regular intervals and plotted in curve form, using time as abscissae and resistance as ordinates. In case the resistance shows a tendency to decrease at first, the drying should continue until the resistance reaches a minimum and has increased again to its proper value. However, where current is not available for drying out, the machine may be surrounded by a sheet iron casing and arrangement made to raise the temperature of the air and the machine inside the case to obtain 100 degrees C, considerable care being taken to avoid exceeding this temperature. This method is quite slow and is usually not considered as satisfactory as when using current in the machine. In this connection, see article on "Drying Out the Dayton Lighting Plants" in the JOURNAL for January, '13. R. A. M.

1085—Radius of Gyration of Motor—Please give a method by which the radius of gyration for the rotating element of a motor is obtained for squirrel-cage, wound-secondary and direct-current rotors. Does it make any difference whether the rotating element is of solid construction or is of spider construction? Is the formula an adaption of similar formula used in calculating beams,etc.? A. E. W. (MARYLAND)

The radius of gyration of a rotor is the point at which, if all the mass could be concentrated, the equivalent flywheel effect would be produced. It is obtained by multiplying the weight of each part of the rotor by the square root of the mean square of its distance from the center in feet and dividing the sum by the total weight. The electrical characteristics of the rotor do not effect the radius of gyration. In practice, the radius of gyration varies in length from 80 to 85 percent of the radius of the rotor, depending upon the mechanical construction of the machine. It is difficult to obtain the exact radius of gration of a built up body that is not of uniform section, as each part must be calculated separately. By dividing it into a number of parts of approximately uniform section, a sufficiently close result may be obtained for practical purposes. For instance, the radius of gyration of a ring of rectangular section with an inner radius of two feet and an outer radius of three feet is $\sqrt{\frac{2^2+3^2}{2}} = 2.55$ feet. Any body can be divided into a number of rings of approximately uniform section. The formula is not the same as for the radius of gyration of a beam. W. S

1086—Demagnetizing Exciter Field—By accident, our 7.5 kilowatt direct-current exciter was connected to our 360 kilowatt, 3-phase, 11 000 volt, revolving field alternator which blew fuse *1*, Fig. 1086 (a). The field rheostat of the exciter was connected

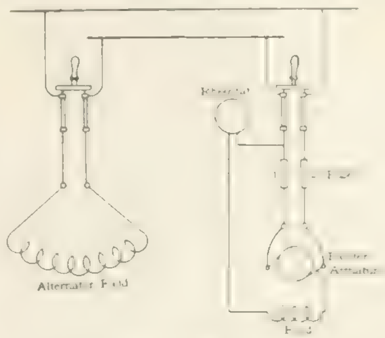

Fig. 1086 (a)

back of this fuse so that when it blew the exciter fields were opened and the lights went out. Upon examination it was found that the field of the exciter was entirely demagnetized. What is the cause? L. A. P. (OHIO)

When fuse *1* blew out, it removed the armature voltage from the alternator fields and left the alternator field connected to the shunt fields of the exciter. The self-induction of the alternator fields set up a current in the fields of the exciter in a reverse direction from normal and consequently demagnetized that machine. D. H.

1087—Generator Regulation—We have a 40 kw, 80 to 160 volt, 250 ampere, three-wire compound generator direct connected to a three-phase motor and used for charging storage batteries. The voltage regulation of the generator is very poor when operating as a 120 volt two-wire machine. What change would you advise me to make in order to operate the generator satisfactorily at 120 volts? E. B. H. (MO.)

Presumably the trouble experienced is that the generator will not hold up its voltage with a load. If this is a non-interpole machine, the brushes are probably shifted forward of the neutral position. If this is the case, the brushes should be placed as near the neutral position as they will stand without sparking. If this does not give sufficient compounding, it will be necessary to supply series field coils having more turns than the present coils. This condition might also be caused by the series field coils bucking the shunt field. D. H.

1088—Insulation Burn-Out—[illegible] how many minutes may elapse before the insulation of a high speed water-wheel-driven generator which is short-circuited will reach a smoking temperature? R. B. G. (CALIF.)

This depends so much on the ratio of short-circuit to rated current, on the current density at which the copper is worked, on the kind of insulation used and, in some cases, on the relative effectiveness of the ventilation, that no average figures can be given. Furthermore, "smoking" is very questionable measure of damage to insulation, since smoking may be due to oils or gums in the insulation and not indicate actual damage to the main insulating materials. In any particular case, the resulting temperature can be calculated on the assumption that all of the generated heat is stored in the coils, in which case three watts will raise one pound of copper one degree C. per minute. F. D. N.

1089—Oscillations Due to Air Break Switch—Assuming that a trans- [illegible] k.v.a. is disconnected from the line by an air break switch, will other apparatus not be affected by the oscillations which may be expected to result from the arc and its final rupture? Will the blowing of a high amperage fuse on the line have the same effect? The line is 200 miles in length, voltage 75 000, and several transformer banks are connected. R. B. G. (CALIF.)

Generally speaking, an air break switch is more liable to cause voltage oscillations by reason of the possibility of opening the circuit while the current wave has considerable value when an air switch is used. The value of the disturbance is wholly controlled by the particular conditions, such as what percentage of the total load is disconnected and its location in relation to other loads. With other loads of considerable magnitude reasonably close to the load disconnected, no unusual disturbances would result, as any oscillations would be absorbed by the load. Some disturbances would result with any standard form of switching if the load was a large portion of the whole. J. N. M.

1090—Locomotive Design—Please inform me if the draw-bar pull due to the side rods on one side of the "Pennsylvania" locomotive motor is constant, neglecting friction. It is understood that the rods on the opposite sides of the locomotives are set at 90 degrees, but it is claimed that if there were rods on one side only the draw-bar pull would still be constant. [illegible]

No. If the Pennsylvania locomotive motor were equipped with a single rod on one side only, the locomotive would not operate. The condition is roughly analagous to a single cylinder crank-connected engine, in which case if sufficient speed is attained to allow the flywheel effort to carry over the dead center, the engine can run, but once stuck on dead center no amount of effort applied to the driving end can pull the engine off the dead center. G. M. E.

1091—Synchronous Motor Driving Pump—(a) How would a 60 kw, three-phase, 60 cycle, 440 volt, 900 r.p.m. generator of the revolving field type and of modern design be expected to behave at starting when used as a synchronous motor direct-connected to a centrifugal pump. The load upon the motor at starting is very small, being practically that due to the friction of the bearings and stuffing boxes. As the pump speeds up the load increases until at 900 r.p.m. the power required is 75 horse-power. Under these conditions, is it possible that as the speed and, therefore, the load increases, at some certain speed the motor will be unable to further accelerate even with the full voltage applied to the stator and will run at a speed less than synchronism. (b)—What would be the approximate k.v.a. input to the motor at synchronous speed before closing the direct-current field circuit and with 440 volts applied to the stator? (c)—Suppose the motor to be speeding up and to have attained a speed of 800 r.p.m. with normal

operating voltage applied to the stator. At this instant the direct-current is applied to the fields so as to give normal field excitation. What would be the effect upon the line current? Would the rate of acceleration of the motor be affected?

J. S. G. (OHIO)

(a)—Centrifugal pumps, in general, require from 25 to 40 percent of full-load torque at starting and an equal, or greater, amount when up to speed. For such a pump, the generator in question would not develop sufficient torque unless it is equipped with a damper winding. If equipped with a damper winding, it is probable that the generator will start the pump, but it is doubtful if it will bring it up to full speed, if 75 horse-power is required at this point. Its characteristics, however, will depend on the details of the generator design. (b)—If the generator does approach normal speed as an induction motor with a 75 horse-power output and no field excitation, the k.v.a. input is apt to be from two and one-half to three and one-half times normal. This input also depends on the design details. (c)—With the machine operating at 800 r.p.m. the effect of applying the field excitation will depend on whether or not the machine is sufficiently close to synchronism to pull into step. If the machine pulls into step, the line current will decrease, but if it is not sufficiently close to synchronism to pull into step as a synchronous motor, the speed will drop and the line current be increased.

R. A. M.

1092—Calculating of Resistances—In Fig. 1092 (a) M_1, M_2, and M_3, are the terminals of a delta connected alternator. a = internal resistance of alternator between terminals M_1 and M_2; b = internal resistance of alternator

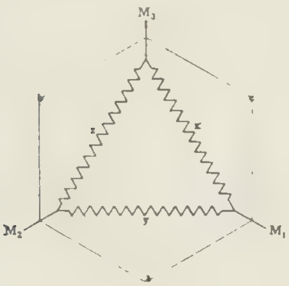

FIG. 1092 (a)

between terminals M_2 and M_3; and c = internal resistance of alternator between terminal M_1 and M_3. What are the resistances of the windings x, y and z in terms of a, b and c?

H. A. V. (DIST. OF COL.)

The resistance measured across any two terminals of a delta connected generator is the combined resistance of two windings in series placed in parallel with a third winding. Assuming resistances x, y and z the same, the individual resistances of windings x, y and z should be one and one-half times the measured resistance across either a, b or c. If the resistances x, y and z are not equal their values may be determined from the following formulae:

$$x = \frac{c-b}{2} + \frac{a(3b + c - a)}{2(b - c + a)}$$

$$y = \frac{a-c}{2} + \frac{b(3c - a - b)}{2(c - a + b)}$$

$$z = \frac{b-a}{2} + \frac{c(3a + b - c)}{2(a - b + c)}$$

J. B. G.

1093—Synchronous Motor with Open Field Circuit—Have any synchronous condensers been designed so that they may be left connected to the line with the field switch open? It would seem that it might be advisable to allow the machine to act as an induction motor for a limited time when severe trouble is encountered on a long transmission line.

R. B. G. (CALIF.)

Any synchronous condenser of modern design may be left on the line for a limited time with no field excitation. There are two possible benefits to be derived from cutting off the excitation during short circuits or similar conditions on a transmission line: (a)—With no field excitation the condenser will take a large lagging current which will tend to reduce the line voltage, thus reducing the severity of any short-circuit conditions; (b)—With no field excitation, the ability of the condenser to feed current into the short-circuit is removed.

R. A. M.

1094—Accuracy of Instrument Transformers—Must switchboard instruments of one manufacture be used with transformers of similar make to obtain rated accuracy? What error if any, may be introduced by using Westinghouse instruments with General Electric transformers?

R. B. G. (CALIF.)

Transformers of a given nominal ratio are assumed to be interchangeable when used within their specified limitations of secondary loading.

P. M.

1095—Rotary Converter with One Phase Grounded—One phase of the three-phase high tension transmission line became accidentally grounded, causing the direct-current circuit breakers on the 550 volt, 1 100 ampere, 25 cycle, shunt wound convertes in a station fed from this line to open. The alternating-current circuit breakers remained closed, being equipped with over-load releases only, while the direct-current circuit breakers had an additional no voltage release whose circuit would also open at an increase in speed. In less than a minute after the direct-current circuit breakers opened, the field cores and dampening rings became red hot. The alternating-current switches were then opened by the operator. The recording wattmeter then showed that the converters had drawn 150 kilowatts apiece while they were running with the direct-current circuit breakers open. The converters were started up shortly after and have since run as well as before. We would greatly appreciate an explanation as to why the pole pieces became red hot.

H. E. M. (MISSOURI)

Presumably, the accidental grounding of one phase of the three-phase high tension transmission line caused a partial short-circuit on the system, resulting in a great unbalancing of alternating voltages. Presumably (owing to the drop in alternating voltage) the direct current reversed, tripping out the direct-current circuit breaker. The converter was then left running on this unbalanced voltage and, due to pulsating armature flux, excessive currents were induced in the squirrel-cage winding and pole pieces. We have heard of trouble before with squirrel-cage windings of rotary converters when operating on unbalanced voltage. To make this explanation reasonable we assume that what is described as a "no-voltage release" on the direct-current circuit breaker is in reality a reverse current relay.

J. L. Y.

1096—Short Circuited Alternator—One phase of a loaded polyphase generator is short-circuited. Under usual conditions what percentage of normal voltage may be induced in the phase or phases not short-circuited? Is this induced voltage of a sustained or transient nature?

R. B. G. (CALIF.)

When one phase of a loaded polyphase generator is short-circuited, the resulting short-circuit current will affect the voltage of the other phase windings to some extent through the action of the flux set up by the short-circuit current. Since, however, these phase windings form closed circuits (due to the fact that these phases are loaded), the change in voltage will be inconsiderable. If these phases were on open circuit, the change in voltage would be greatly increased, although no average figures can be given. The amount and direction of the change in voltage will depend upon the amount and direction of the short-circuit current. This, in turn, depends on the design proportions of the generator or generators concerned and on the value and direction of the voltage wave at the instant of short-circuit. These voltages induced in adjacent windings are, of course, transitory since the current and flux producing them are transitory. However, if the short-circuited condition continues long enough for steady current to be reached, the induced voltages due to this current will also be steady.

F. D. N.

1097—Heat Efficiency of Steam Turbines—(a) For various sizes of turbines from say 1 000 to 20 000 kilowatts, what percentage of the net heat absorbed by the turbine is available at the generator terminals? (b) Is the efficiency as designated above the same for low pressure turbines working on exhaust steam as for high pressure turbines of the same size?

B. T. M. (QUEBEC)

(a) Turbines are compared on the Rankine cycle efficiency basis. For instance if a turbine has a Rankine cycle efficiency of 75 percent, that machine utilizes 75 percent of the available energy in the steam passing through it. By available energy is meant the B.t.u. drop (per pound of steam for instance) from the inlet to the exhaust, the action being considered purely adiabatic. The turbine Rankine cycle efficiency and economy is affected as follows:

1—The larger the machine the better the economy.
2—The higher the peripheral speed the better the economy. The higher the rotative speed in r.p.m. the higher the peripheral speed (generally speaking).
3—The less the heat range or B. t. u. drop the better the Rankine cycle efficiency. Of course the greater the heat range the better the actual economy in pounds of steam per kw-hour.

In commercial machines the economy and Rankine cycle efficiency increases with the size, and for 1 000 kw and 20 000 kw units operating at the same steam conditions, the Rankine cycle efficiencies are about 57 and 75 percent respectively. The efficiency increases a great deal more rapidly directly above 1 000 kw than it does directly below 20 000 kw. The figures of 57 and 75 percent would be better, of course, if the turbines only were considered, the betterment obviously being directly affected by the generator efficiencies, the 57 percent being proportionally more

improved, as the generator efficiency is not so good for the smaller unit. (b) As is commonly known, approximately the same amount of energy is available below atmospheric pressure as above. There are three classes of turbines that may be considered; the high pressure condensing, the high pressure non-condensing and the low pressure machines. As stated above, the less the heat range or B.t.u. drop, the better the Rankine cycle efficiency and so roughly, the high pressure non-condensing and low pressure machines of the same rating, operating over the same heat range, are in a measure equally efficient, each being more efficient (on the Rankine cycle basis) than the high pressure condensing machine. The less the heat range in any particular type of turbine, each designed for the range over which it operates, the greater the Rankine cycle efficiency. Of course, there are other factors affecting the Rankine cycle efficiency besides the heat range. For instance the low pressure turbine of the same size and operating over the same heat range as the high pressure non-condensing turbine is the more efficient of the two. This is due principally to the blading being more efficient and leakage less as the specific volume, and so actual volume handled are a great deal greater in the low pressure turbine, making it possible from a practical standpoint to use higher blade speeds, larger and so more efficient blading. Generally speaking, the percent of moisture is less in low pressure turbines which, with other factors pertaining to the design of each machine, also effects the efficiency. C. M. H.

1098—Dynamic Braking—Has dynamic braking for direct-current hoisting cranes proven itself satisfactory, and do you know of any large installations that have been discarded for mechanical brakes? If so, why? J. S. (QUEBEC)

Dynamic braking is being used on practically all modern cranes with magnet switch control, even on open hearth, hot metal cranes where safety and reliability are prime factors. They are used in connection with magnetic brakes which are designed merely to hold the load. The motors are series wound and the lowering connection is with armature and series field in parallel giving a shunt motor characteristic. If the load overhauls the motor regenerates, otherwise it takes some power from the line. In the off position the motor armature is practically short-circuited on the series field and the line switches are opened. Mechanical air brakes are still used to some extent on mine hoists and ore bridges, possibly because electric brakes have not yet been developed for motors of the larger sizes. We do not know of any installations which have discarded the dynamic braking scheme after a thorough trial. J. H. A.

1099—Induction Motor with Phases Cross-Connected—The stator winding in a 2 200 volt, three-phase, 50 horse-power induction motor was damaged. In being repaired two phases in the winding were cross-connected. The motor would run on the 1 100 volts starting voltage but when the line voltage was turned in it would blow the fuses and trip the oil switch. Why did it not blow the fuses at starting? J. G. W. (PENNA.)

As no information is given it is a matter of surmise as to just what the improper connection may have been and its probable effects. It seems reasonable to infer that the nature of the so-called "cross connection" is such as to cause excess current to flow which is proportional to the voltage impressed on the motor. When the motor is on half voltage this excess current is not sufficient to blow the fuses, but when the motor is on full voltage it reaches a value which destroys the fuses. Another circumstance which may have some bearing on the case is that the fuses which are used on the starting side of the auto-starter or compensator are ordinarily of much larger capacity than those on the running side. This might account for an abnormal current not blowing the starting fuses, whereas the same current would immediately blow the fuses on the running side. A. M. D.

1100—Impregnating a Solenoid—I am designing an iron-clad plunger electromagnet in which I propose to use enameled copper wire of about No. 20 gauge. I propose to insulate the coil from the bobbin and outer iron by sheet mica. Is it desirable to impregnate the coil with some compound to more readily conduct the heat from the inside of the coil, and if so, what compound should be used and how should this be applied? The magnet is intended to run as hot as the insulation will permit. L. A. H. (NEW JERSEY)

Cotton covered wire should be impregnated with bakelite or some compound which will give similar protection. No impregnation is necessary with enameled wire. W. O. L.

1101—Phasing-Out Generators—With two generators connected as shown in Fig. 1101 (a), and a connection such that the motor runs in the same direction when connected to each generator, would it be safe to connect the two generators together, as shown,

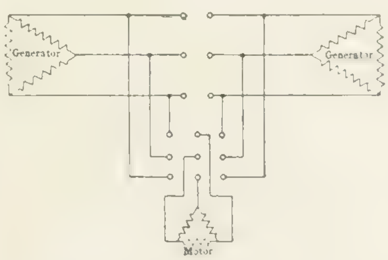

FIG. 1101 (a)

after synchronizing. In other words, is the use of a motor in this way a safe method for phasing out two generators? J. P. L. (NEVADA)

This method of testing connections for synchronizing is entirely satisfactory and is one constantly used where a suitable small motor is available. R. A. M.

1102—Single-Phase Motor—I have a 60 cycle, single phase, 240 volt, two-pole Duntley electric drill, the rotating armature of which has ten slots and apparently ten coils but has twenty commutator bars and a connection to each bar. Will you kindly explain the winding and connecting of this armature? R. L. T. (IND.)

This motor is wound with two coils in the bottom and two coils in the top of each slot and is connected up in the usual manner. The two coils in each slot are wound as one with a loop brought out from the center of the coil in effect forming two coils, but having the external appearance of only one. C. B. C.

1103—Removing Old Insulation—Can you give me some kind of a chemical solution for removing the old insulation from armature core slots that would have no injurious effects on the iron of the core itself, to be used in a shop where a large number of armatures have to be rewound regularly? H. R. A. (N. Y.)

A solution composed of 25 percent alcohol and 75 percent benzole is good for loosening the varnish of old insulation so that it can be scraped from the slots in the armature. This will produce no bad effects on the laminations or on the winding when the armature is rewound. Alkali solutions such as caustic soda will also loosen the insulation without injury to the laminations, but would creep between the laminations and after the armature is rewound the alkali fumes would damage the insulation. A tool made from bar steel one by one-sixteenth inch, of suitable length and drawn down to a long thin point like a chisel answers very well to remove old insulation after it has been softened, and will also give very satisfactory results without the use of any chemicals whatever. After removing the insulation in this way a file is drawn through the slots for a final cleaning. J. L. R.

1104—Arc Welding—I have some armature shafts with the key ways badly worn in. Will you please tell how to build them up by the electric arc process. Also what flux is to be used. I have a 500 volt, 500 ampere motor-generator set that I can use and can cut the voltage down to about 100 volts. H. E. W. (UTAH)

To build up armature shafts which are of clean steel—a metal electrode 3/16 inch diameter by approximately 10 or 12 inches in length and of cold rolled steel should be used, though Norway or Swedish iron may also be employed. The voltage of the machine may be as high as 100, though this is not necessary; in fact, the voltage of the machine is usually about 70, that across the arc about 30, the difference being consumed by a steadying resistance in much the same manner as in an arc lamp. The current taken will then be from 130 to 160 amperes. The positive terminal should preferably be connected to the shaft, thus making the electrode negative. The weld is made by manipulation of the electrode, regulating the length of the arc and keeping it sustained while at a distance of 3/16 inch or more away. Should the electrode become too hot, the voltage should be reduced and vice versa; no flux is necessary. For further details see the JOURNAL for Jan., 1908, p. 18, and for Jan., 1914, p. 37; and the "*American Machinist*," March 16th, 1911; also questions 802, 551 and 248. C. B. A.

1105—Formula for Meter Transformers—When using potential transformers in connection with wattmeters, voltmeters and meters in general where it is necessary to change the potential to suit the meter voltage, what formula should be used to determine the necessary capacity of the potential transformers? C. M. (CALIF.)

Transformers should have primary voltage ratings within 20 percent of the primary voltage to be applied. This will be line voltage in most cases or 58 percent of line voltage for three-phase four wire or Y connections. The current ratings can be determined from the losses in the meters to be supplied. The losses in alternating-current voltmeters are

from eight to ten volt-amperes; watt-hour meters not over two to three volt-amperes; indicating wattmeters about five volt amperes; power-factor meters about ten volt amperes; synchroscopes about ten volt amperes. If the meters differ much in power-factor the vectorial sum of the currents should be used. Synchroscopes are connected to the meters for such a short period of time that their load is not usually considered in determining the capacity of potential transformers. Meter readings are multiplied by the ratio of transformation. For example a 2 000/100 volt transformer makes a certain reading represent twenty times the load corresponding to the same reading without the transformer. H. B. T. & W. R. W.

1106—Storage Battery Operation—I have a set of storage batteries which I am using for residence lighting. These batteries are the pasted type and have a capacity of about 120 ampere-hours. I charge them at a rate of 12 amperes for three hours once per week with the regular overcharge. The discharge averages about two amperes for three hours per day. Is it necessary that the specific gravity of the electrolyte be maintained at 1.285 at the end of charge on this class of service? There are a few cells that I have charged at the rate of nine amperes for 36 hours and at the end of charge and five hours previous, the specific gravity reached 1.250 and after discontinuing the charge and the batteries had stood for two hours out of service, the specific gravity dropped to 1.210. What is the cause of this? The sediment in the bottom of the jars is not near the plates. If I can get a voltage of 2.5 per cell with the electrolyte at 1.210, are not the plates less apt to sulphate, than with the gravity of 1.285? What is the proper care to give these batteries for this class of service and obtain the maximum life of the plates?

J. O. W. (N. Y.)

Charge the battery up full, then take the elements out of the jars and put in new wood separators. Throw all the old acid away, and wash out of the jars thoroughly. Put the elements back into the jars and pour in acid with a specific gravity of 1.300. Then put the battery on charge at not more than nine amperes until it shows full capacity. It is necessary that the electrolyte show a specific gravity of from 1.280 to 1.290. The plates will sulphate more quickly when the specific gravity is about 1.210 than when at 1.285. F. A. S.

1107—Air Compressor Operation—(a) In Westinghouse air compressors, why is the center line of the crank shaft lower than the center line of the cylinders? (b) What effect does this have on the piston speed of the compression and suction strokes? (c) What effect does this have on the pressure on the crank shaft bearings and the wear of the piston rings on the cylinder walls? (d) What would be the result of running a compressor reversed, taking the case of a compressor with crank shaft bearings that do not entirely surround the shaft as the D2 EZ type and with bearings such as the C-60 type? Also what would be the effect on the herring-bone gear of running reversed?

L. M. W. (NEW YORK)

(a) This is for the purpose of obtaining a more direct thrust on the pressure stroke than is possible if the center line of the crank shaft and the cylinder are the same, thus reducing friction losses. (b) This increases slightly (about two percent) the average piston speed on the suction stroke, and decreases the average piston speed by the same amount on pressure stroke. (c) It increases the pressure on the crank shaft bearings but to an inappreciable extent. It does not affect the wear of the piston rings on the cylinder walls. (d) With either kind of center bearing, reversing the compressor increases the pressure on these bearings. The effect of reversal on the gear would be a decrease in the pressure tending to separate the halves of the gear, whereas in the pinion the tendency to separate the two halves is increased. In small pinions, trouble might result from rotation in the wrong direction. P. L. C.

1108—Power-Factor Curve — What would be the approximate characteristic power-factor curve of a 20 horsepower, two-phase, 60 cycle squirrel cage induction motor at 100 percent overload? What effect does a voltage that is considerable above rating have upon a standard motor as described above as regards efficiency and power-factor? C. D. R. (OHIO)

This would depend to a very large extent on the value of the maximum or pullout torque as compared to the normal full-load torque. That is to say, a motor having three to four times normal torque as its maximum torque would have a higher power-factor at 100 percent overload, as compared with the full-load power-factor, than would a motor with a maximum torque one and three-fourth to two times normal. This condition varies also with the number of poles the motor has. In general it is reasonable to assume that the power-factor at 100 percent overload will be less than at full load but the amount of this variation may be from zero to 15 percent or even more in extreme cases. Answering the second question the general effect of an increase in voltage which does not exceed ten percent of normal is to leave the efficiency practically unchanged and reduce the power-factor a small amount. Variations of over ten percent have a tendency to decrease both power-factor and efficiency and increase the heating. A. M. D.

1109—Inherent Reactance—Please explain clearly how the inherent reactance of a generator is determined when the term is used in connection with the rating of oil circuit breakers. Volume X, p. 1107, states it is assumed "that the generators have an inherent reactance of approximately eight percent, or in other words, give a maximum current on the first wave of short-circuit of 12.5 times the mean full-load current; and also that the sustained short-circuit current has a maximum value of three times the mean full-load current." What is meant by "mean full load current?" Is it the root mean square value of the full load current? Volume XI, p. 199, states that the maximum value of the first wave on short-circuit is to the maximum value of the full-load current as 180 is to the percentage reactance. In this case the reactance is spoken of as transient reactance. It also states: There is no justification, in spite of its frequent use, for the simple relation that the maximum value of the first wave of short-circuit is to the maximum value of the full load current as 100 is to the percentage transient reactance." From this article it would appear that inherent reactance and transient reactance are two different quantities but it does not appear that the ratio of 100-180 bears any relation to the ratio between the maximum value of the full-load current and its root mean square value. J. P. (ALBERTA)

Inherent reactance and transient reactance are different names for the same quantity. The statement in Vol. X, p. 1107, is incomplete. As explained in Vol. XI, p. 199 the maximum short-circuit current in a generator having eight percent transient reactance is approximately $180 \div 8 = 22.5$ times the normal current, peak values in each case being considered. As explained in Vol. XI, the ratio of 100 to 180 is approximately the ratio of short-circuit current value when the short-circuit wave is symetrical with respect to the zero line of current to the short-circuit current value when the short-circuit wave is displaced entirely to one side of this zero line. The relation of the short-circuit wave to the zero line depends on the value of e.m.f. at the instant of short-circuit. The term "mean full-load current" used in the article referred to is the root mean square value as stated on the name plate of the machine or obtained by a meter reading. The term "percent inherent reactance" as used by circuit breaker engineers is for the purpose of defining the relation of the value of initial maximum short-circuit current of a generator to the name plate continuous full-load rating.

F. D. N. & J. N. M.

1110—Selection of Carbon and Graphite Brushes—(a) What are the relative merits of graphite brushes as compared with carbon and what conditions, such as commutator speed, slotted or unslotted mica, etc., govern the proper selection of either type? (b) Since there are various grades of both carbon and graphite brushes, what factors enter into the proper selection of a grade of hardness of either type?

G. V. A. (CAPE BRETON)

(a) In general, carbon brushes are more abrasive than graphite brushes and, therefore, are better for flush mica. Carbon brushes have greater electrical resistance than graphite brushes and must be used where the voltage under the brush is excessive. Graphite brushes have better lubricating qualities, better conductivity and lower contact resistance than carbon brushes and, except for the above mentioned conditions of unslotted mica and excessive brush voltage, graphite brushes are more efficient than carbon brushes. High speed commutators require brushes haying the best lubricating qualities. (b) Most brushes are made from a mixture of carbon and graphite, varied with reference to desired resistance, abrasiveness and hardness. Resistance and abrasiveness are the factors governing the selection of a grade of hardness. In some cases toughness or resistance to chipping has to be considered. The manufacturers have mechanical tests which determine the toughness of their products. With brushes made from mixtures of carbon and graphite, toughness is the result of manufacturing methods rather than of proportion, although a pure graphite brush is never as tough as a pure carbon brush. H. R. E.

THE ELECTRIC JOURNAL

VOL. XI SEPTEMBER, 1914 No. 9

Induction Motor Characteristics

The articles by Messrs. Weber and Motyer in this issue call attention to the value of reconsideration from time to time of first principles. Inherently, no new facts are deduced, but old facts are presented in an interesting way and new data is added which will be of service to practical users of induction motors, who are seeking analytical answers to physical problems.

There are two valuable points in Mr. Motyer's paper. First, that the speed regulation of phase-wound induction motors with resistance in the secondary circuit is poor at speeds below the normal full-load speed of the motor, and grows poorer, the greater the speed reduction under which the motor is running. A thorough understanding of this point will prevent many disappointments in application and condemnation of the motor for an indifferent performance when nothing else should have been expected. The second point is that induction motors, when run at reduced speeds, suffer a decrease in efficiency almost exactly proportional to the decrease in speed.

There is perhaps no other single subject in connection with alternating-current motors which has received so much attention from technical writers and investigators as the performance of the straight single-phase induction motor. It appears sometimes that the material that has been published on the subject is out of all proportion to the practical use which has been made of the motor itself. The recent advent of various forms of phase converters has aroused new interest since it appears that some systems will be dependent upon apparatus of this type. Mr. Weber's curves are timely in showing exactly what happens to the performance of the single-phase motor under widely varying conditions. These curves answer many of the questions commonly asked about single-phase motors and have the added advantage, as stated in the text, of being a record of actual test results and consequently a true picture within the negligible limits of errors in observation. The polyphase curves are valuable as being a fuller record than is usually obtainable with facilities at hand, and in comparison with the single-phase, accentuate the operating differences in the two types of motor.

Actual data of this nature serves a double purpose in the interest it carries for its own sake, and in furnishing a basis for other investigations to which it is necessarily incidental. A. M. DUDLEY

Flow of Power by Phase Difference

We are accustomed to the idea, based on the fluid analogy, that electric power must flow in the direction of the drop of voltage. This analogy is not fundamentally incorrect, since instantaneous power always does flow in the direction of lower electric pressure. Power may, however, flow from a lower to a higher root mean square voltage. The reason for this is that there are two influences responsible for the flow of power in alternating-current circuits; one is drop in voltage, and the other is phase difference between supply and load. These two causes are not isolated and independent but are closely related and dependent on each other. Under certain conditions of line reactance power can be made to flow toward any load taking a leading current, even though there is a rise of voltage between the supply and receiver ends of the line.

All transmission lines must possess reactance to some degree. If a lagging current passes over a line possessing such reactance the drop in the line is exaggerated since the portion of it which is due to the reactance comes more nearly into phase with the supply voltage. If, on the other hand, an appreciably leading current flows the line drop is reduced or may even become negative since it tends to be in reverse phase to the supply voltage. Obviously a negative drop first takes up the natural loss in voltage due to the resistance of the line and causes the supply voltage and the load voltage to become equal. If there is a still greater leading current there may even be a rise of measured voltage from the supply to the load end of the line and yet power be flowing toward the load all the time. This condition cannot exist, of course, unless there is appreciable line reactance. We see, therefore, how an apparent impediment to the delivery of power may be a blessing, and it may even become necessary to add artificial reactance to the line.

The article in this issue by Mr. H. B. Dwight discusses the methods of calculating the requirements of such a method of power transmission to give constant voltage at the receiving station. The idea is that each load supply the required conditions by so-called synchronous condensers, so that enough leading current will be drawn from the line to produce *constant* voltage regardless of power-factor. Such a system not only minimizes the line loss but enables the line to be designed primarily with reference to the most economic line costs, without reference to the question of regulation. R. P. JACKSON

The Widening Field for Electrical Engineers

The peculiarly intimate interdependence between electric operation and the many activities of modern life calls for men of far wider capability than mere technical skill. For many years the chief endeavor of electrical men was to find out how to generate and distribute electric current. How to make a dynamo; whether to connect lamps in series or in parallel; how to make a motor that could be relied upon to run a street car—such were the problems that pressed for solution. As these problems have been worked out from year to year, power houses have grown larger, transmission and distribution systems have been built, while motors and other appliances for utilizing the current have been developed.

The notable characteristic of the use of electricity is not so much the convenience, simplicity or economy occurring when it is substituted for some other means of accomplishing a given result, as it is that new methods may be adopted and new results may be obtained. As the electric system affords a means of transmitting power produced in large quantity by the most economical means and supplying it for a thousand uses, it comes into intimate and vital relation with all kinds of activities.

New problems are found in the application of electric current so that the mutual adaptation of the electrical devices and the operations to be performed will secure the most effective results. In illumination, for example, new lamps have been perfected which give more light, while on the other hand a study of the way to use light more effectively has led to a new kind of engineering—illuminating engineering. The early idea in the use of motors for driving mills and factories was simply the substitution of motors for an engine to effect a saving in the cost of power. Now the principal aim is to secure a better kind of power by which a superior or cheaper product can be produced, and motors are specially adapted to the particular requirements of each class of service. But the real purpose of the motor is to assist in producing a product and the important problem is to find the modifications in methods or processes, the improvements in operation or reduction of losses, which will lead to more economic production. This is application engineering. It is one thing to make motors that will run; it is quite another to determine what is possible of accomplishment by electric power and to adapt the motors to the work and the process to the motors not merely with electric efficiency and mechanical reliability, but so as to bring final results which are better and cheaper.

This field of applied electricity knows no bounds. Wherever light is needed, wherever power can be used, wherever heat is to be applied, wherever electrochemical processes are to be carried on, the problem for the application engineer is—How can better results be secured, how can electric service be made to simplify, to improve, to economize, to contribute to convenience and comfort, to promote the general welfare? This larger view of the functions of the electrical engineer has modified and broadened his field of work. Designers must consider the service conditions which their apparatus will encounter and aim to secure the best ultimate result, even though the electrical appliances may cost more. In the sales department the jolly good fellow has given place to the engineer, to the man who knows what can be done and how to do it, who can analyze a situation and predicate what electricity can do to improve or cheapen or to develop new fields, and who can state his case in both technical and commercial terms. This is well brought out in an article in this issue by Mr. S. L. Nicholson. Among central stations there are service departments with experts who can advise as to the best methods of using electricity and the gain in comfort or economy which may result. In all sorts of industries which use electricity there are opportunities for engineers who can study operating methods and can devise new and improved ways.

In the organization of railway, central station and industrial companies many executive and administrative positions are held by men who have been trained as engineers. The knowledge and training which the engineer acquires is found to give the power of analysis and the constructive mode of thought which are valuable in accounting and financial affairs. Municipalities are finding that good engineers, rather than astute politicians, are needed for administering public affairs, building roads and sewers and water works, and for dealing with electric railway and lighting and power matters.

There was once an idea that young men studied electrical engineering so that they might design dynamos and motors. Good designers are still needed, but the number is insignificant as compared with the demands in other fields. Each designer of motors or heating appliances or lamps supplies a hundred application engineers. The power from a single generator is available for a thousand purposes. The problem is to apply and to use, to modify the methods of modern affairs so that they may take full advantage of the new possibilities which electricity has given to the world.

Just as the electrical industry has extended from a small beginning to a universal electric service which is interrelated with innumerable activities, so also has the need for men expanded. At first the technical expert was concerned wholly with things electrical: later has come also the need for men to cope with every department of the extended service; men who know the electrical appliances and who understand the requirements of the many industries which they are to operate; men who can handle practical conditions of every sort, who can deal with business and financial matters, or with public affairs; men of vision and capability who can help to realize in actual performance the possibilities presented by the new source of universal power.

Chas. F. Scott

A Study of Three-Phase Systems

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IT IS PROPOSED in this paper to study several common methods of connecting transformers for use on polyphase systems with the view of displaying the advantages of each, showing under what conditions they may be used to the best advantage.

IT IS well known that the shape of an e.m.f. wave is that of the differential of the flux wave which produces it.* That is, the slope of the e.m.f. wave is a maximum when the slope of the flux wave is a minimum and vice versa. Also this e.m.f. is 90 degrees out of phase with the flux, since the e.m.f. is greatest when the rate of change of flux is greatest.

Take, for instance, a transformer on open circuit. The counter e.m.f. due to self-induction is 90 degrees out of phase with the flux in the core, as shown in Fig. 1, and is, neglecting resistance and leakage, equal to the impressed e.m.f. To produce a sine flux in the iron a current I_o must flow through the windings, which may be resolved into three components; one, I_ϕ, is a distorted wave, having its peak coincident with the peak of the flux wave, but

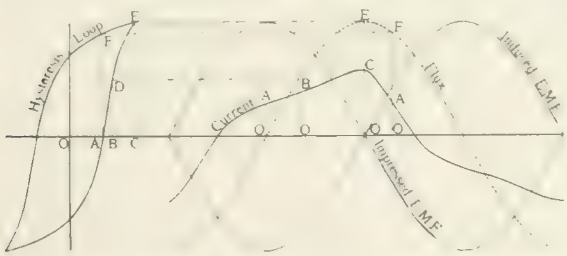


FIG. 1—CURRENT WAVE REQUIRED TO PRODUCE SINE WAVES OF FLUX AND E.M.F.

The current wave was derived by plotting points obtained from the flux wave and the hysteresis loop. Thus, on a basis of one turn, the distance *OA* on the hysteresis loop equals the distance *OA* on the current curve at the instant of zero flux. This current curve corresponds very closely with similar ones obtained by oscillographic records.

crossing the zero at different times, the distortion being due to the varying permeability of the magnetic circuit; and two others, I_e, representing the energy loss due to eddy currents, and I_h, representing the loss due to hysteresis, both of which are sine waves, directly in phase with the impressed voltage. I_ϕ can be analyzed into a fundamental and a number of higher harmonics, of which the third is most pronounced. The shape and amplitude of the exciting current wave may be obtained from the hysteresis loop, as shown in Fig. 1, in which the ordinates of the current curve are taken from the abscissae of the hysteresis loop for particular values of flux which, for any value of time, are taken from the flux curve. If the harmonics are absent from the exciting current the result will be a distorted flux wave, such as shown in Fig. 2, the principal harmonic being the third.*

STAR-STAR CONNECTION

In the primary of a star-connected group of transformers the sum of the currents flowing towards the neutral point must be zero. The triple harmonic components of the magnetizing current in a symmetrical three-phase system, when present, have the same phase relations to their respective fundamentals and the fundamentals are 120 degrees apart. Therefore the three triple harmonics are exactly in phase, as shown in Fig. 4, and since in the star connection their sum must be zero, each component is necessarily zero. This suppression of the third harmonic component of the magnetizing current will cause third

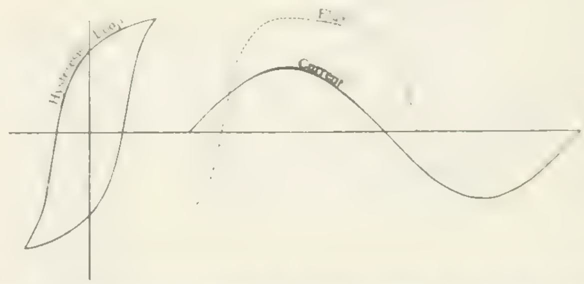


FIG. 2—FLUX WAVE PRODUCED IN IRON HAVING THE GIVEN HYSTERESIS LOOP BY A SINE WAVE OF CURRENT

This is the condition produced in a current transformer, where the current wave is determined by conditions external to the transformer.

harmonic components to appear in each of the three-phase e.m.f's. between the neutral and the mains, which, when the system is perfectly symmetrical, are exactly equal and in phase with one another. Since the e.m.f. between any two terminals is equal to the vectorial difference between the e.m.f's. from the neutral point to those terminals, the triple harmonic e.m.f.'s existing in the two latter will cancel each other and will not appear in the wave form between terminals.

Thus, the presence of the third harmonic in the e.m.f.'s between the neutral and mains of the primary circuit does not materially affect the e.m.f. between lines in the secondary circuit. However, a load cannot be taken off between the neutral point

*This is evident from the equation $e = \frac{d\,\Phi}{d\,t}$.

*The elimination of third harmonics in three-phase transformation as referred to subsequently, does not include any of the higher harmonics, except those which are multiples of three. While the fifth, seventh, eleventh, etc., harmonics have usually a measurable value, their effect can be neglected, since they can never enter into a single-phase relation.

and one of the lines, because this e.m.f. is unstable. The reason of this is evident from an inspection of Fig. 3, in which the voltage between lines *AB, BC,* and *CA* is held constant by the generator. If a load is taken from the secondary as shown, the secondary current in *O′ C′* will cause a primary current to flow

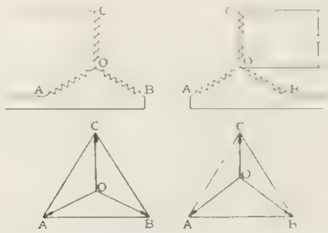


FIG. 3—SHIFTED NEUTRAL IN A STAR CONNECTION

in *OC,* having nearly equal and opposite ampere turns to that in *O′ C′*. This current must be supplied through the primaries of the other two phases *AO* and *BO* which have no corresponding current in their secondaries; consequently these windings act as very high impedance choke coils in series with the transformer *OC* and thereby the impressed e.m.f. across *OC* is reduced to a small value.

One method of obtaining a stable neutral point is to connect the primary neutral to the generator neutral. A constant e.m.f. (that of one phase of the generator winding) is thus maintained across the transformer primary *OC* which will hold up the voltage on the load and prevent shifting the neutral. The objection to this is that if the generator e.m.f. has a third harmonic component, and the secondary system is grounded, there is a corresponding third harmonic potential present in the secondary system between the transmission line and ground which may cause a very large third harmonic charging current to flow through the transmission line, returning through the earth. This charging current may be greatly enhanced by partial resonance, due to the reactance of the transformers and lines. The chief trouble due to the third harmonic charging currents is caused by the highly inductive path through which they flow, the fields set up thereby causing inductive interference with neighboring telephone or telegraph circuits.

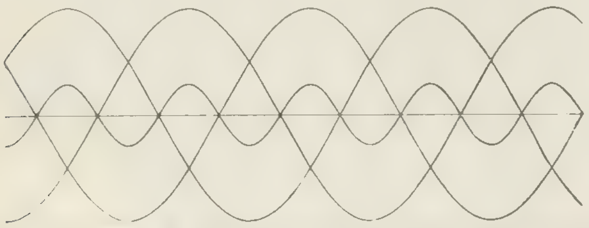


FIG. 4—RELATION OF THIRD HARMONICS WHEN FUNDAMENTALS ARE 120 DEGREES APART

In single-phase transformers and three-phase shell-type transformers this third harmonic component of the wave form may be entirely eliminated by using an interconnected-star secondary winding; and if care be taken to properly interlace the windings, as shown in Fig. 5, the neutral point will be stable and a load may be taken from the secondary circuit between the neutral and lines, even though the primary neutral is not connected to the generator neutral. In this case the triple harmonic e.m.f.'s in the two halves of each coil are opposed and hence annul one another. The primary should

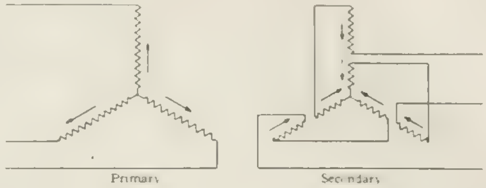


FIG. 5—INTERCONNECTED STAR SECONDARY CONNECTIONS

not be interconnected, if the neutral is connected to the generator neutral, for if the generator has a third harmonic component it will flow through the two windings of one transformer in opposite directions; the impedance to the flow of the third-harmonic current set up by the third-harmonic component in the generator e.m.f. wave between neutral and terminals is thereby rendered very small and these currents may be large enough to cause undue heating. The action in this case is like that of a single-phase e.m.f. impressed on two equal coils of a transformer connected in opposition. The single-phase fluxes are opposed and there is no opposition to the triple harmonics except the leakage flux.

In three-phase core-type transformers, that is to say, transformers with interlinked magnetic circuits, this same interchange of magnetomotive forces takes place between the phases, so that each phase has a part of the magnetomotive force supplied by the other two phases during a portion of the cycle, as shown in Fig. 6. In this case if there is no leakage, all the flux going up in one part of the magnetic circuit must go down in some other; that is, the algebraic sum of the three magnetic fluxes must be zero; therefore the sum of the three induced e.m.f's. must also be zero and thus the neutral point is the centroid of the primary voltage triangle. In such transformers there exists a third-harmonic leakage field in the air external to the coils due to the above mentioned interchange of

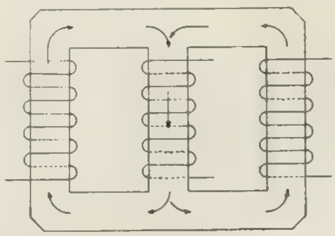


FIG. 6—FLUX PATHS IN A THREE-PHASE CORE TYPE TRANSFORMER

third-harmonic e.m.f., but its value is very small with transformers having small magnetizing currents. The neutral point will be symmetrically located, even with wide differences in the permeability of the cores, the required e.m.f's. for the three cores being supplied in the proper relation by the three primary windings.

The magnetizing currents in three-phase transformers of this type which are unsymmetrical have third-harmonic components, which are in three-phase relation and produce unlike waves in the three phases.

If a load be taken from one phase of the secondary of a three-phase transformer of the type under discussion, a leakage field is set up in the coil spaces between the loaded phase and the other two which is usually large. The regulation of such transformers for loads between the neutral and lines is not usually good. The condition is similar to the effect of loading one side of a single-phase core-type transformer connected for three-wire distribution which had not been designed with cross-connected secondary windings. Interconnection of the primary or secondary windings is one remedy for this trouble.

In the straight star-connection with single-phase transformers, the voltage stress per turn on the windings is quite high on account of the excessive peaking of the e.m.f. between neutral and lines. The core loss of the transformers is usually lower than for a sine wave e.m.f. even though the effective value of the neutral to line e.m.f. is more than 57 percent of the e.m.f. between lines. Formerly it was considered a grave disadvantage of this connection that a short-circuited unit would cause 73 percent increase in stress on the other two. It is not probable now that such a condition could exist without tripping the breakers, since this increase in voltage with the steel now used in transformers would result in a magnetizing current having an effective value several times the full-load current.

The advantage of the star-star connection of single-phase transformers is in its simplicity and low cost. It is not suitable for four-wire three-phase distribution, nor should it be operated with the neutral grounded. The transformers are subjected to an undue stress between layers and between coils on account of the distorted e.m.f. between neutral and lines. If the neutral of the primary be connected to the neutral of a generator which has no third-harmonic component the connection may be used for four-wire three-phase transmission with or without the neutral point grounded. The advantage of simplicity and low cost is lost to a great extent if it is found necessary to interconnect the windings on account of the desirability of grounding the neutral point.

Three-phase transformers star-star connected may be used with or without the neutral grounded, for three-phase three-wire transmission. Light loads may also be taken off between neutral and line. Interconnecting the low-tension winding does not involve much trouble, but it is simpler to connect this winding delta, which produces the same result in a simpler and more efficient manner.

Star-star connected three-phase transformers have the same advantage as single-phase transformers connected in the same manner, and the stress to which the insulation is subjected may be reduced to a smaller value for a given voltage between terminals than with any other connection; this advantage, however, is of little consequence when the line e.m.f. is low. They have the additional advantage that the e.m.fs. between neutral and lines do not have a third harmonic.

DELTA-DELTA CONNECTION

This connection is the most widely used of all three-phase connections, and is recommended for moderately high voltages on account of its extreme flexibility The third harmonic and its multiples are eliminated in the terminal e.m.f.s. of a symmetrical star-connected generator, and if the three delta connected transformers are alike in design and magnetic characteristics they will be absent in the secondary e.m.fs. Differences in magnetic characteristics of the transformers are corrected in this connection by interchange of m.m.f. through the secondary windings. A marked dissymmetry in the bank of transformers may cause a third-harmonic component in three-phase relation to appear in the secondary e.m.fs. between lines; but the usual third-harmonic distortion characteristic of the secondary e.m.f. of single-phase transformers is not present in the e.m.f. between phases, due to the fact that the delta-delta connection affords a low impedance path to the flow of current set up by such a component, thereby automatically eliminating it. In three-phase transformers of the form known as core-type, the interlinking magnetic circuits of the three phases somewhat modify the interactions between the three phases but the differences in action from single-phase transformers connected in delta are trifling.

The chief advantage of the delta-connected group of single-phase transformers lies in its flexibility. If one of the transformers in a group fails the other two are able to supply power at a diminished rating, the only change being the cutting out of the defective transformer, which may be done without interference with the operation of the other two.

The stresses to which the insulation is subjected are higher than in the star connection, and there is no means of grounding the neutral except through the intermediary of an interconnected star group of single-phase auto-transformers or a three-phase auto-transformer, or some such device, provided with a star connection.

STAR-DELTA AND DELTA-STAR CONNECTION

These methods of connecting transformers have been the subject of a good deal of controversy, and have suffered through misapplication. It was pointed out that in the star-star connection it was necessary to interconnect the primary winding to eliminate the distorting third harmonic and to obtain a stable neutral point; this is effected in the delta-star connection of single-phase transformers at a minimum cost, and with a maximum degree of stability of the neutral point. It is in reality a more direct transformation

than the delta-delta connection; since there can be no interchange of m.m.f. between phases, the secondary neutral to line e.m.f. is the same as that obtained with single-phase transformation and may contain a trace of third harmonic due to the reactive drop of the exciting current.

The three-phase core-type transfomer with delta-star connection has a stable neutral point and also on

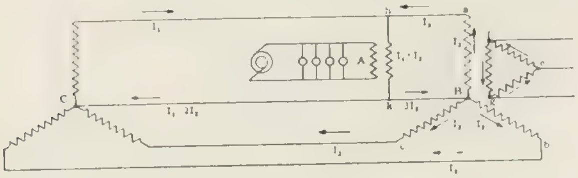


FIG. 7—ILLUSTRATING THE REGULATING EFFECT OF A STAR-DELTA CONNECTED GROUP OF TRANSFORMERS ON A THREE-PHASE FOUR-WIRE SYSTEM

account of the interlinked magnetic circuits the secondary neutral to line e.m.f. is absolutely free from third harmonic. The three-phase shell-type does not differ materially from three single-phase transformers.

The star-delta connection has some very interesting peculiarities, lack of understanding of which has led to its improper use, resulting in troubles which have been considered as the fault of the connection, rather than of the individuals who misapplied it. In this connection the sum of the secondary induced e.m.f's. must be zero on account of the delta-connected secondary; consequently the neutral point of the primary star connection must be the centroid of the primary e.m.f. triangle except for the slight distortions caused by the drop due to the exciting currents in the windings. It has already been pointed out that a third-harmonic component is required in the m.m.f. wave to produce a sine wave of induction. If the primary is star connected, this third harmonic m.m.f. is supplied to each phase as required by the other two through the secondary delta-connected winding, so that there exists a circulating third-harmonic magnetizing current in the delta, which is equal in magnitude and time phase to the equivalent component in the normal single-phase secondary exciting current of the transformers. The effect of differences in the magnetic characteristics of transformers so connected is to cause a slight dissymetry in the secondary e.m.f. waves between lines, which is due to the third-harmonic components in three-phase relation which appear in these e.m.f's.

If the neutral of a star-delta connected bank of transformers be connected to that of the generator supplying the transformer the result will be a short-circuit so far as the third-harmonic component of the generator between neutral and terminals is concerned, the flow of third harmonic current being limited only by the impedance of the transformers, and very serious heating may result both to the generator and to the transformer. Since the neutral of the transformer is stable there is no necessity for connecting it to that of the generator, and if it is desired to ground the primary system this may be done most advantageously by grounding the neutral point of the bank of transformers.

The delta-star connected three-phase transformer, or bank of transformers, is suitable for three-phase transmission and distribution with both three and four wires. A load taken off between neutral and line will cause the neutral to shift only an amount equal to the impedance drop of the transformer supplying the loaded phase. In four-wire three-phase systems, where the e.m.f. is stepped up through delta-star transformers, and three-phase power is supplied through star-delta step-down transformers the latter, if their neutral be connected to the neutral wire, serve as balancers for loads taken off between the neutral wire and the lines. Fig. 7 will suffice to explain this action of the star-delta connected bank of transformers.

Let C be the source of supply, A a heavy single phase user and B a small three-phase user. With a heavy load on A the voltage hk will drop and energy will be fed not only from the source, but also through phases bB and cB. The voltage on fg will also tend to drop because of the lower voltage on aB. The voltage on ef and eg will cause a circulating current to flow around the delta efg which not only serves as a magnetizing current to hold up the voltage on aB but also supplies actual energy to aB by drawing current through the windings bB and cB from the lines. Thus bk may be considered as supplied directly from station C and also indirectly through the secondary delta efg. This characteristic may cause a serious heating of the three-phase transformer.

An interesting peculiarity of the star-delta connection is that when the wave form of applied e.m.f. is not a sine wave, a peaking harmonic in the e.m.f. across the lines will produce a flatting harmonic in the

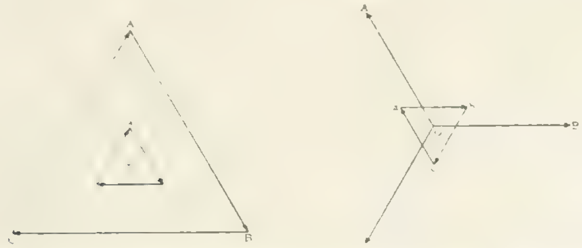
FIG. 8—THE SUM OF TWO FLAT-TOPPED WAVES IS A PEAKED WAVE

e.m.f. between neutral and lines as shown in Fig. 8, and vice versa, although the effective values will be in the ratio of 1 to $\sqrt{3}$, as for a sine wave; as a consequence the core loss of a three-phase star-delta connected transformer may have different values when measured on the star side and delta side, when the form factor of the impressed wave differs from that of a sine wave.

The star-delta and delta-star connection have all the advantages of the star-star connection without their grave disadvantages. As pointed out before, when the e.m.f. is low there is no inherent advantage in the star connection. Actually, however, there may be decided disadvantages. There is no advantage in supplying a single-phase load from the neutral point of a generator; on the contrary the single-phase output of a three-phase generator is greatest when the power is supplied from two terminals. The delta-star connection permits of this and therefore increases the unbalanced capacity of the whole system. Consequently, even should it be possible to entirely eliminate the third harmonic from the e.m.f. wave between the neutral and terminals of a generator, the star-star connection is hopelessly out of the running when it has to compete with the delta-star connection. In three-phase transformers the delta-star connection is the most economical way of obtaining good regulation between neutral wire and lines in a three-phase four-wire system.

DISCUSSION OF DELTA-DELTA AND DELTA-STAR SYSTEMS

For three-phase transmission at moderate voltages, say up to 33 000 volts, the advantage lies with



FIGS. 9 AND 10—POTENTIAL DIAGRAMS OF DELTA-DELTA AND STAR-DELTA CONNECTED TRANSFORMERS, NORMAL OPERATION

the delta-delta connection for single-phase transformers, on account of its greater flexibility and because the failure of one unit in a bank interrupts service for only the short length of time required to cut out the defective unit, operation being continued with the transformers connected in V at a reduced rating.

For three-phase four-wire distribution the delta-star and star-delta connected transformers are most suitable. It may not be out of place here to sound a note of warning in connection with supplying single-phase service from three-phase sources grounded or ungrounded. In a single-phase transformer connected to a three-phase system, the secondary winding has a potential determined by the mean-potential of its primary winding and the relative capacity between primary and secondary and between secondary and ground. An ungrounded secondary winding which is disconnected from other wiring may have quite a high potential due to this effect. A preferable way of supplying residence lighting from a three-phase line would be by means of a three-phase step-down transformer or bank of single-phase transformers connected in star-delta or interlinked six-phase, then if the supply circuit were grounded at the neutral point, the secondary circuit could be operated ungrounded with safety. The practice of running single-phase feeders from a three-phase supply to outlying districts for the purpose of supplying lighting service is bad in so far as when the secondaries are grounded it is liable to interfere with telephone service.

For three-phase transmission at voltages above 44 000 volts, the problem of insulation begins to assume importance. Figs. 9 and 10 are potential diagrams of delta-delta step-up or step-down transformers and delta-star step-up or star-delta step-down transformers. The point *O*, the centroid of the potential triangle, is at zero potential; the potential of any portion of the winding of any phase is given by the distance of the equivalent point on the potential diagram from the centroid. The e.m.f's. and instantaneous potentials are given by the projection of the points *A B C, a b c* on a given line passing through *O*, the vectors being considered as rotating about *O* so as to make one complete revolution per cycle. Comparing these two potential diagrams, it will be apparent that the high-tension winding of the delta-star transformer is subject to lower average stress than that of the delta-delta, the stress in the first connection varying from 0 to 57.7 percent of the line e.m.f. and in the second from 28.8 to 57.7 percent of the line e.m.f.

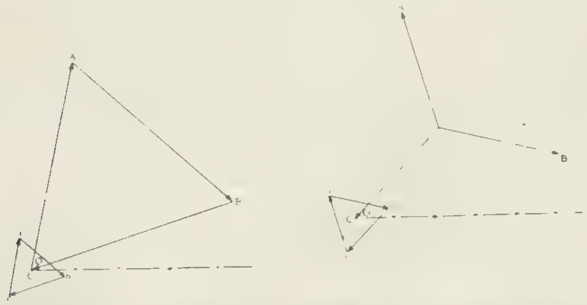
The tendency of any connection to give trouble during switching will probably depend largely on the amount of potential energy stored in the system under normal operating conditions. The high-tension windings of the transformers in both connections will have about the same capacity to ground, the tendency being for higher values in the transformers for the delta-delta connection. If *E* be the effective value of the e.m.f. between lines, the maximum amount of energy stored in the dielectric will be in the case of the delta-delta connection for each transformer $CE^2 \div 6$, and in the case of the delta-star connection it will be $CE^2 \div 9$ for each transformer, the value *C* being the total capacity of the high-tension winding of each transformer to ground.

It follows in consequence that there will probably be fewer disturbances caused in a transimssion system when a star-delta bank is switched on and off the circuit than when a delta-delta bank of the same capacity is switched on and off; and therefore the insulation stresses due to switching in the star-delta connection will be correspondingly smaller than in the delta-delta connection. The same relations hold true for any conditions that may arise in operation which cause the circuit breakers to open, such as a ground on the line, short circuits between phases, etc. In every case the energy stored in the dielectric is less for the star-delta connected group than for the delta-delta connected group.

The dangers arising from switching are caused not so much by the rapid interruption of large cur-

rents (for as a matter of fact the rate of diminution at the instant of interruption is not very much greater than if the circuit breaker remained closed), as by the potential energy in the disconnected bank of transformers and transmission line becoming changed into kinetic energy after the current has ceased setting up oscillations in the two systems which produce differences of potential at the disconnecting points sufficient to cause them to arc over. These abrupt changes in condition set up other trains of oscillation which are superimposed on the first, resulting in abnormal stress on the insulation of the transformers.

When the line is disturbed by lightning, the capacity of the transformers will have little to do with the severity of the disturbance. The charge due to a thunder-cloud, when released, sets up waves which on striking the transformers cause a high stress between adjacent turns of the windings, particularly those near the terminals. A large capacity between adjacent turns will tend to reduce the severity of these stresses. In the star high-tension winding the large wide conductors tend to large values of capacity between adjacent turns, which is the condition required for reducing the stresses.



FIGS. 11 AND 12—POTENTIAL DIAGRAMS OF DELTA-DELTA AND STAR-DELTA CONNECTED TRANSFORMERS WITH ONE LINE GROUNDED

The delta-star grouping has the advantage from an insulation standpoint even if the neutral point is not grounded. With a grounded neutral point the insulation stress is still further reduced, an advantage which cannot be obtained with the delta-delta system without auxiliary star-delta transformers.

The mechanical stresses due to short circuit will be the same for both systems, but delta high-voltage windings are not so well adapted to withstand mechanical shock as the stauncher windings for star connection. It may therefore be stated that, with equal mechanical support, the delta high-voltage winding will be mechanically weaker than the corresponding star winding.

Cost.—The coils used in all power transformers of large capacity are discoidal, sometimes termed pancake coils, and consist of spirally wound flat copper ribbon conductors insulated with sleeves or strips of micanite or other insulating material. To enable the workman to produce a servicable coil the conductor must be large enough to hold down the sleeves or layers of insulating materials, otherwise the coil will be "mushy." However carefully a "mushy" coil may be clamped up and treated it can never be as strong mechanically as one more solidly constructed of heavier conductor. More care is therefore involved in winding such coils, in their preparation for treatment and in their handling after treatment, during assembly. The cost per turn per coil is therefore higher, as is also the cost of treatment and handling per coil. There are 73 percent more turns in a complete delta winding than in a star winding, and an equivalent larger number of coils. The cost of the complete winding will therefore be considerably more for the delta than for the star system.

In assembling, each coil has its own individual insulation; each lead must be tied to its proper position. The coils in a group must be placed in position one by one during assembly and the connections soldered. There are therefore more operations in the assembly of a delta winding than in that of a star winding and the coils have to be handled with more care. The cost of assembly will therefore be higher for the delta-connected than for the star-connected transformers.

Since the conductor to be insulated is smaller in the transformers of the delta group than in those of the star group, the insulation will occupy relatively more space in the former, with the result that the dimensions of the transformers for delta connection will be larger and they will require more active material than those for the star connection.

A transformer designed for delta-star connection is less costly to manufacture than one designed for delta-delta connection. The high-tension wiring of a group of star-connected transformers is simpler than that for a group of delta-connected units, which is no inconsiderable advantage with high transmission voltages.

POSSIBILITIES OF DEVELOPMENT

The above discussion applies to present standard practice. Considered from the point of view of future development, the advantage is all with the delta-star and star-delta connections. Thus, for example, the worst condition of stress in the transformers arises when one line becomes grounded. The potential diagrams for such a condition are given in Figs. 11 and 12. The delta group has a maximum stress varying from line voltage to 87.7 percent of the line voltage; in the star group the maximum stress varies from line voltage down to 57.7 percent of the line voltage. If full advantage be taken of this difference, the cost of the transformers for star connection will be lowered still further. With the advantage afforded by grounding the system at the neutral point, the star-connected group may be manufactured at a very much lower cost than the delta-connected group.

As improvement in methods of switching will enable the manufacturer to take further advantage of the lower stress to which the star-connected group is subjected under operating conditions, considerable de-

velopment may therefore be expected in this direction in the future.

PAST AND PRESENT PRACTICE

In view of the fact that the largest and most successful power transmissions in America are operated with delta-star step-up star-delta step-down transformers, and that several among them, together with a large number of smaller power companies, have been in operation for a considerable length of time, it seems somewhat superfluous to bring up arguments in support of this method of connecting transformers. Following is a list of power transmissions using transformers star-connected on the high-tension side which have been in operation for a considerable length of time.

Ontario Power Company .... [illegible] volts
Southern Power Company ...... 100000 "
Ontario Hydro-electric Power Commission .... 110000 "

Table I gives a list of power companies transmitting at 70,000 volts and above; 23 of the 37 use transformers which are star-connected on the high-tension side. One of the most recent is the large power development of the Mississippi River Power Company, the Keokuk development transmitting power at 110 000 volts. Perhaps the most notable of recent power developments is that of the Pacific Light & Power Company, transmitting at 150 000 volts, which employs the delta-star connection.

It will be evident from this table that the advantages of the delta-star connection are recognized by a large number of engineers; but it should be used universally for transmission voltages above 66 000 volts instead of in a little more than 50 percent of the cases as the table indicates.

For transmission voltages below 44 000 volts, transformers with either star or delta-connected high-tension windings may be used; the delta connection has a slight advantage due to its greater flexibility.

For transmission voltages above 44 000 volts, transformers with star-connected high-tension windings should be used.

These conclusions are based, not so much on theoretical considerations as upon the results of actual experience in the manufacture, installation and operation of transformers on systems employing both the delta-delta and delta-star connections. The delta-star system has been consistently advocated for high voltage transmission for over a decade. During the early part of the history of the electrical industry, at a time when very few high voltage transmissions existed, this attitude was subject to much criticism, but time and experience have provided the justification of the system.

TABLE I—AMERICAN POWER COMPANIES TRANSMITTING AT [illegible]

NAME	Operating Voltage	Frequency (cycles)	Capacity of plant (kilowatts)	Beginning of operation	Phases	[illegible] Low	[illegible] High	[illegible]	[illegible]	[illegible]	Dist. of [illegible] (miles)
Pacific Light & Power Co.	[illegible]	50	[illegible]	1913	1	Δ	Y	D.	[illegible]	[illegible]	[illegible]
Au Sable Elec. Co.	140000	[illegible]	[illegible]	1912	1	Δ	[illegible]	No	[illegible]	[illegible]	[illegible]
Southern Sierras Power Co.	140000	60	[illegible]		1	Δ	Y	R	[illegible]	[illegible]	[illegible]
Utah Power & Light Co.	[illegible]	[illegible]	[illegible]	[illegible]	1	Δ	[illegible]	No	Δ	[illegible]	[illegible]
Pacific Gas & Electric Co.	12[illegible] to 11[illegible]	60	25000	[illegible]	1	Δ	Y	D.	[illegible]	[illegible]	[illegible]
Tennessee Power Co.	[illegible]	60	15000	1914	3	[illegible]	[illegible]	No	[illegible]	[illegible]	[illegible]
Connecticut River Transmission Co.	[illegible]	60	[illegible]	1914	3	Δ	Y	D.	Y	Y	[illegible]
Inawashiro Hydro-Electric Power Co.	115000	50	[illegible]	1914	1	Δ	Δ	No	[illegible]	[illegible]	[illegible]
Grand Rapids-Muskegon Power Co.	110000	30	[illegible]	[illegible]	[illegible]	Δ	[illegible]	No		[illegible]	[illegible]
Lauchhammer, A. G.	110000	50	[illegible]	1911	[illegible]	Y	Y	No	Y	Y	[illegible]
Ontario Hydro-Electric Commission	110000	25	[illegible]	1910	1	Δ	Y	R	[illegible]	Y	[illegible]
Georgia Ry. & Power Co.	110000	60	50000	1912	1	[illegible]	Y	R	[illegible]	Δ	210
Alabama Interstate Power Co.	110000	60	48000	1913	[illegible]	[illegible]	Y	R	[illegible]	Y	150
Mississippi River Power Co.	110000	25	112500	1913	[illegible]	Δ	Y	[illegible]	[illegible]	Δ	144
Mexican Northern Power Co.	[illegible]	60	26000	[illegible]	[illegible]	[illegible]	Y	R	Δ	[illegible]	[illegible]
Lehigh Coal and Navigation Co.	110000	25	[illegible]	1914	[illegible]	Δ	Y	R	[illegible]	[illegible]	24
Ebro Irrigation & Power Co., Ltd.	[illegible]	50	50000	1914	1	Δ	[illegible]	No	Y	[illegible]	[illegible]
Chile Exploration Co.	[illegible]	50	40000		[illegible]	Y	Y	[illegible]	[illegible]	Y	[illegible]
Sierra San Francisco Power Co.	[illegible]	60	34000	[illegible]	[illegible]	Δ	Y	D.		Y	[illegible]
Yadkin River Power Co.	[illegible]	60	21000	1912			Y	D.			[illegible]
Great Falls Water Power & Townsite Co.	102000	[illegible]	[illegible]	1910	[illegible]	Δ	[illegible]	[illegible]		Δ	[illegible]
Central Colorado Power Co.	[illegible]	60	[illegible]	1909	[illegible]	[illegible]	[illegible]	No	Δ	[illegible]	152
Great Western Power Co.	100000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Δ	[illegible]	[illegible]
Southern Power Co.	[illegible]	[illegible]	[illegible]	1909	1	[illegible]	Y	R	[illegible]	Δ	[illegible]
Shawinigan Water & Power Co.	100000	60	45000	1911	[illegible]	[illegible]	Y	R	Δ		[illegible]
Los Angeles Aqueduct	100000	[illegible]	[illegible]	[illegible]	1	Δ	Y	[illegible]	[illegible]	Y	47
Tata Hydroelectric Co.	100000	[illegible]	[illegible]	1914	1			No	[illegible]	Δ	[illegible]
Appalachian Power Co.	[illegible]	[illegible]	20610	1912	[illegible]	[illegible]	[illegible]	[illegible]	Δ		[illegible]
Rio Janiero Tramway, Light & Power Co.	[illegible]	50	[illegible]	1913	1	[illegible]	[illegible]	[illegible]	[illegible]	Δ	[illegible]
Sao Paulo Elec. Co.	[illegible]	[illegible]	30000	[illegible]	1	[illegible]	[illegible]	No	Y	Δ	
Mexican Light & Power Co.	85000	[illegible]	58500	1910	1	[illegible]	Y	D.	[illegible]	Y	[illegible]
Victoria Falls & Transvaal Power Co.	84000	[illegible]	[illegible]	[illegible]	[illegible]	Δ	Y	R	Y		[illegible]
Toronto Power Co.	[illegible]	25	80000	1914	1	[illegible]	[illegible]	No		Δ	[illegible]
Katsura Gawa Denryoku Kabushiki Kaisha	77000	[illegible]	[illegible]	[illegible]	1	Δ	Y	R	Δ		[illegible]
Southern California Edison Co.	[illegible]	[illegible]	[illegible]	[illegible]	1	[illegible]	Y	[illegible]	Δ	Y	[illegible]
Hidro-Electrica Espanola Molinar	[illegible]	50	[illegible]	1910	[illegible]	Y	Y	No	Y	Y	[illegible]
Pennsylvania Water & Power Co.	70000	[illegible]	71500	1910	3	[illegible]	Y	R	Y		[illegible]

Direct-Current Motor and Generator Diagrams

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ANY ONE change in the operation of a direct-current machine of necessity brings about changes in dependent or related characteristics and, although a first consideration of their relations would indicate a hopeless number of permutations of conditions in the machine circuit, it will be found on closer analysis that they can be reduced to a few simple groups covering practically the complete range of direct-current operation. In the following article, given sets of conditions are selected as working standards and on that basis a thorough study is made of the direct-current machine, the results being given for reference in tabular form, together with the corresponding diagrams of connections. This data should serve in practice exactly the same function as a formula for common use, the more or less complicated derivation of which is not necessary in its every application.—Ed.

IN THE INSTALLATION and operation of direct-current apparatus minor changes are often required to meet altered conditions of service; changes from a motor to a generator, or vice versa; changes in direction of rotation, or changes in equalizer or main bus polarity. These alterations usually affect the internal connections of the machine, and this discussion illustrates diagrammatically such modifications of the connections between the different parts of the electric circuit as may be required in the more common instances.

Operating conditions involving such alterations may be classified as changes:—

1—From operation of the machine as a generator (Standard Figs 3 and 11).
  a—To continue as a generator but under different conditions of rotation or polarity (Figs. 4 to 10).
  b—To operation as a motor (Figs. 12 to 27).
2—From operation of the machine as a motor (Standard Figs. 28 and 44).
  a—To continue as a motor but under different conditions of rotation or polarity (Figs. 29 to 43).
  b—To operation as a generator (Figs. 45 to 52).

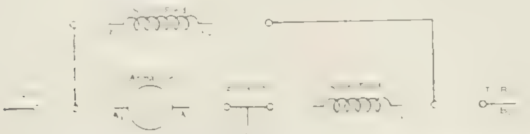


FIG. 1—DIAGRAM INDICATING THE PARTS OF THE DIRECT-CURRENT MOTOR OR GENERATOR CIRCUIT WITHOUT CONNECTIONS
This diagram is common to Figs. 3 to 52, inclusive.

The principal operating conditions involved in such changes are as follows:—

1—Main terminal or bus polarity.
2—Direction of rotation.
3—Series and equalizer polarity.
4—Direction in which the field excitation builds up.
5—The action of the series field—compounding or differential.

For each of these factors there are only two possible conditions; that is, two directions of rotation, two directions of shunt field current, two kinds of terminal or equalizer polarity, and either compound or differential relation between the shunt and series fields. Therefore, when the diagrams* indicate that the polarity or arrangement of wiring connections for any part of the electric circuit is the same after as before the changes made, these conditions are denoted as *standard* in Table I; if these conditions are different, after making changes, from those given in the standard diagram, they will be indicated in the table as *reversed*.

In considering the figures illustrating the above cases the following points should be observed:—

1—The diagram in Fig. 1 is common to all figures.
2—A standard method of indicating reversal of connections for each part of the electric circuit is employed as shown in Fig. 2.
3—Direction of rotation is indicated by an arrow inside the armature.
4—Direction of current flow in field coils and armature is indicated by the arrows shown adjacent to those parts. The direction of magnetization corresponds to the direction of current indicated in the shunt field.
5—A compounding (additive) relation is assumed as standard between shunt and series excitation for all figures. Differential action is indicated by the reversal of one or other of the arrows (not both) representing direction of excitation of shunt and series coils.

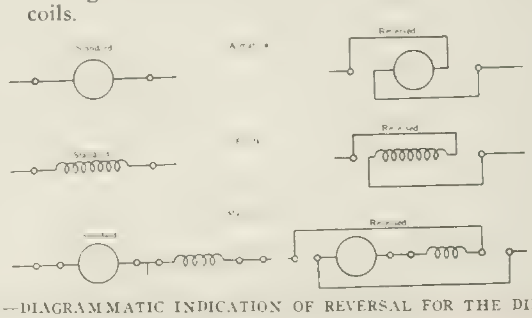


FIG. 2—DIAGRAMMATIC INDICATION OF REVERSAL FOR THE DIFFERENT PARTS OF THE CIRCUIT
Standard for all figures which follow.

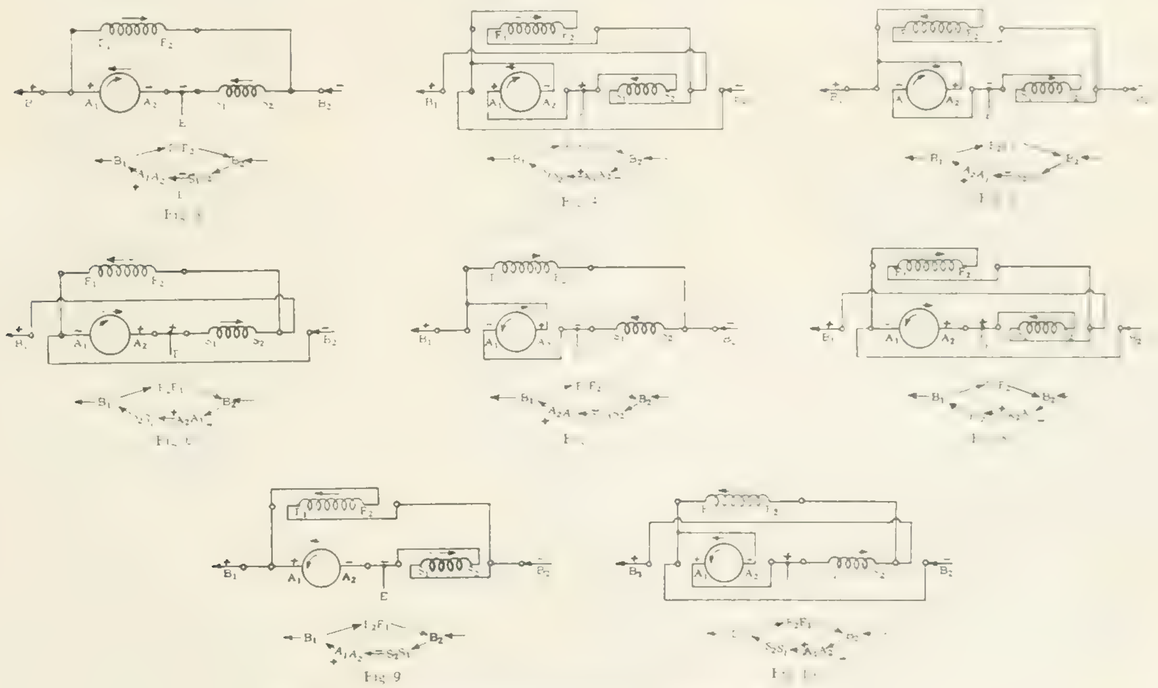
6—The equalizer is located in all the diagrams, between the armature and series field. It will be observed that the "long shunt" field connection has been indicated in all figures; for "short shunt" connection, move the shunt field lead now attached to the terminal on the line side of the series field to the point at which the equalizer is connected; no further alteration will be needed.
7—The standard assumed for main terminal or bus polarity is:
  a—Positive for the generator terminal from which current flows to the line.
  b—Positive for the motor terminal to which current flows from the line.*
8—Figs. 3, 11, 28 and 44 are standard diagrams illustrating the electric circuit relations for standard operation before making any of the changes specified in their respective sections. They are, therefore, the standards of comparison for the figures immediately following, all of which are drawn up to indicate the electric circuit relations after necessary modifications have been made in the standard diagrams to suit the altered conditions of service specified.

*The particular diagram adopted as a standard is entirely arbitrary. Figures made up for comparison with one standard would necessarily differ from those made up for comparison with a different standard; the actual change in wiring however to effect any specified relation between the five factors given above would be the same whatever diagram is adopted as a basis of comparison. Table I is therefore suitable for general application.

*Generally speaking, the positive terminal is always the terminal at which delivery of current is made from the source of supply to the load, and similarly, the negative terminal that where current returns from the load to the source of supply.

EXCITATION AND POLARITY

As all the diagrams for generator action are made up for self-excited machines, a word of explanation and of emphasis in regard to the method of building up and of reversing terminal voltage is included. All machines have a certain amount of magnetism left in the core after the exciting current is broken. When self-excited, it is this remanent magnetism which enables them to build up voltage when starting again after a period of rest. The action is cumulative; that is, a low voltage is induced in the armature by the remanent flux, sending a small current through the field when its circuit is closed. The resulting slight addition to the existing magnetism induces a slightly higher voltage and so on, the cycle being repeated until full voltage is reached.



FIGS. 3-10—DIAGRAMS CORRESPONDING TO CASE I OF TABLE I

Fig. 3 is taken as the standard diagram for generator operation; that is, the bus polarity, direction of rotation, equalizer polarity, direction of shunt field excitation and the action of the series field as well as the connections for each, are regarded as standard; and where any one of these conditions or connections is tabulated as "reversed" in the table it indicates that it is the opposite of that for the standard diagram.

If, on the other hand, it is desired to reverse the polarity of the machine and with this intention the terminals of the self-excited shunt fields are reversed, it is evident that the voltage which is generated from the remanent flux causes a current to flow in the field coils in such a direction as to tend to set up a flux opposing the remanent flux, and the machine cannot build up. Reversal of the polarity of the machine, therefore, can only be accomplished by "flashing," that is, by externally exciting the shunt field in the opposite direction with a small amount of current and flashing or breaking this until a voltmeter across the terminals indicates that the machine can build up in the opposite direction. The field can then be reconnected for self-excitation.

Accidental flashing or reversal of polarity sometimes occurs when the field or load circuit is suddenly subjected to very heavy fluctuations. When facilities are not available for reflashing after such an occurrence, and immediate service is important, temporary reconnection of armature and field leads may be employed to maintain service. Such reconnection is illustrated in Fig. 5 and is one of the numerous though less common applications of the tabulation given in this article.

METHOD OF DERIVING THE DIAGRAMS

In explanation of the method for deriving the diagrams, assume the condition of a compound-wound generator which has "bucked" off the line and reversed its polarity. Assume also that it is desired to parallel the machine with another whose equalizer lead is on the positive side, instead of the negative which is standard, Fig. 3. Before putting it back in service the prime mover is altered as well and its direction of rotation reversed. On the basis that the polarity at the bus-bars remains unchanged and further that the machine is still to operate compound wound (std.), determine the alteration in wiring connections necessary to connect the machine to the bus-bars without reflashing. This problem is illustrated by comparing Figs. 3 and 10 and the procedure for its solution may be outlined as follows:—

1—Tabulate the five primary conditions according to which the machine is to operate after making the change:

- a—Bus polarity .... Std.
- b—Direction of rotation .... Rev.
- c—Equalizer polarity .... Rev.
- d—Direction of excitation .... Rev.
- e—Series field action .... Cpd.

2—Lay out the preliminary diagram shown in Fig. 1 and refer to Fig. 3 as the standard for generators.

3—Mark the polarity of each part of the circuit as + or — in accordance with the five conditions given above.

a—For standard polarity, the bus bar B_1 (positive) is at left, B_2 (negative) at the right.

b—The rotation is reversed:—therefore the arrow inside the armature is opposite to that of Fig. 3.

c—The armature polarity is determined by the two factors, direction of rotation and direction of excitation. Reversal of either reverses the armature polarity, while reversal of both does not affect it. The latter is the condition in this case:—therefore A_1 and A_2 remain as in Fig. 3; viz. positive and negative respectively.

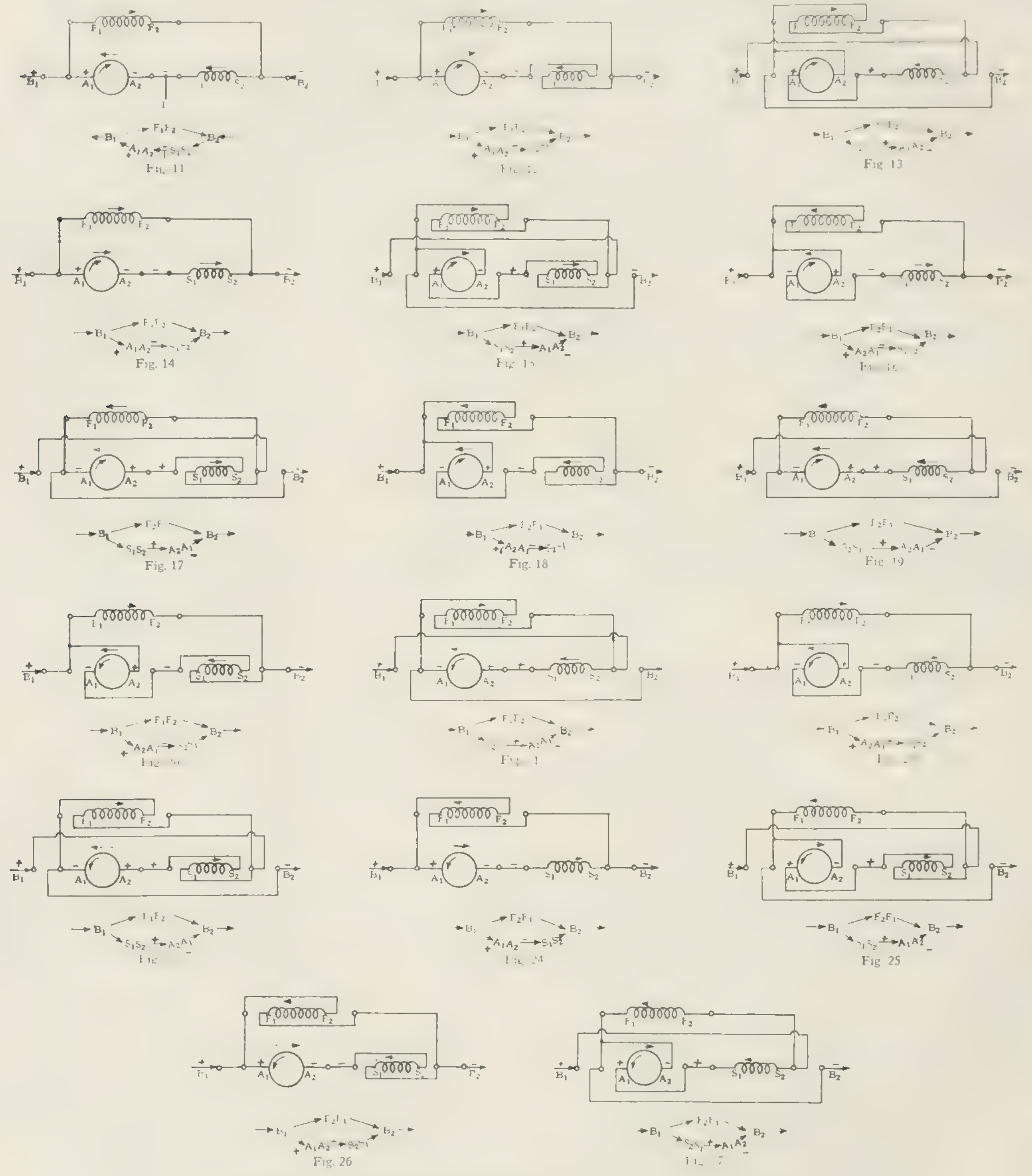
between the armature and series field must be on the positive side of the armature.

e—Current flows from the machine at the positive bus-bar and to the machine at the negative.

5—Add the necessary connections to complete the circuit between the sections to correspond with the direction of current in each.

a—As the equalizer is positive it must be connected directly to the positive terminal of the armature. The armature leads must therefore be reversed.

b—From the equalizer, current can pass directly through



FIGS. 11-27—DIAGRAM CORRESPONDING TO CASE II OF TABLE I

Fig. 11 is the standard diagram for generator operation shown in Fig. 3 and is used as a standard for the figures of this case.

4—Indicate the direction of current in each part of the circuit by an arrow.

a—In the armature of a generator the current flows from the negative to the positive terminal; in the armature of a motor, the current flows from the positive to the negative terminal.

b—As the direction of excitation is reversed in this case, the shunt-field current arrow will be reversed.

c—As the field windings are connected compound, the series-field current arrow will also be reversed.

d—As the equalizer polarity is reversed, the connection the series field as indicated by the series field current arrow previously assigned.

c—From the series winding the connections must be to the positive bus-bar, thereby reversing the main leads.

d—Direct connection through the shunt field from the positive terminal of the machine checks with the direction of the arrow.

All the conditions specified in this case can therefore be fulfilled by reversing the armature leads and by reversing the main terminal connections.

USE OF THE TABLE AND DIAGRAMS

The above method of procedure was employed in the construction of each of the accompanying figures, and in Table I are tabulated all the combinations of conditions likely to be met with in practice. Having a given set of conditions to fulfill, the necessary steps in using the tabulated data together with the corresponding figures, are as follows:—

1—Determine which of the four given cases covers the one in question.

2—Refer to this case in Table I and locate the conditions to be met by the change.

3—The wiring changes required are those specified in the last four columns of Table I in the same horizontal line with these conditions and the number at the extreme left of the same line is that of the corresponding diagram of connections.

[illegible]

Commutating-pole windings have been omitted from the foregoing for simplification. In all commutating-pole machines the armature and commutating-pole windings must be considered as a unit. The reversal of one necessarily means the reversal of the other. Two methods for accomplishing this reversal are possible:—

1—When the armature and commutating pole windings are adjacent in the wiring layout, as is almost invariably the case, one connection between the armature and commutating pole windings may be considered as fixed under all conditions (Fig. 54) and reversal may be accomplished by interchanging the two outer leads.

2—The terminals of both armature and commutating pole windings may be individually reversed (Fig. 55) either by

FIGS. 28-43—DIAGRAM [illegible]

Fig. 28 is taken as the standard for motor operation in the same manner as Fig. [illegible] was regarded as standard for generators. Accordingly the material in Table I referring to Figs. 28 to 43 refers to Fig. 28 as the basis of comparison.

TABLE I—SUMMARY OF WIRING CHANGES FOR ALTERING CONDITIONS OF SERVICE IN THE OPERATION OF DIRECT-CURRENT GENERATORS AND MOTORS

Case I—Machine operating as a *generator* before change (Standard Diagram Fig. 3). To continue operating as a *generator* after change, but under new conditions specified.

Conditions of Operation							Excitation		Wiring Connections			
Fig. No.	Operation	Bus-Bar Polarity	Direction of Rotation	Series and Equalizer Polarity	Std. or "Flashed" Fld. Polarity	Compound or Differential Series Fld.	Direction of Shunt Current	Direction of Series Current	Main Leads	Armature Leads	Shunt Field Leads	Series Field Leads
*3	Gen.	Std.	Std.	Std.	Std.	Cpd.	Std.	Std.	Std.	Std.	Std.	Std.
4	Gen.	Std.	Std.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Rev.	Rev.	Rev.
5	Gen.	Std.	Std.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Rev.	Rev.	Rev.
6	Gen.	Std.	Std.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Std.	Std.	Std.
7	Gen.	Std.	Rev.	Std.	Std.	Cpd.	Std.	Std.	Std.	Rev.	Std.	Std.
8	Gen.	Std.	Rev.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Std.	Rev.	Rev.
9	Gen.	Std.	Rev.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Std.	Rev.	Rev.
10	Gen.	Std.	Rev.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Rev.	Std.	Std.

Case II—Machine operating as a *generator* before change (Standard Diagram Fig. 11). To operate as a *motor* after change, under conditions specified.

*11	Gen.	Std.	Std.	Std.	Std.	Cpd.	Std.	Std.	Std.	Std.	Std.	Std.
12	Mot.	Std.	Std.	Std.	Std.	Cpd.	Std.	Std.	Std.	Std.	Std.	Rev.
13	Mot.	Std.	Std.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Rev.	Rev.	Std.
14	Mot.	Std.	Std.	Std.	Std.	Diff.	Std.	Rev.	Std.	Std.	Std.	Std.
15	Mot.	Std.	Std.	Rev.	Std.	Diff.	Std.	Rev.	Rev.	Rev.	Rev.	Rev.
16	Mot.	Std.	Std.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Rev.	Rev.	Std.
17	Mot.	Std.	Std.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Std.	Std.	Rev.
18	Mot.	Std.	Std.	Std.	Rev.	Diff.	Rev.	Double Rev. —Std.	Std.	Rev.	Rev.	Rev.
19	Mot.	Std.	Std.	Rev.	Rev.	Diff.	Rev.	Double Rev. —Std.	Rev.	Std.	Std.	Std.
20	Mot.	Std.	Rev.	Std.	Std.	Cpd.	Std.	Std.	Std.	Rev.	Std.	Rev.
21	Mot.	Std.	Rev.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Std.	Rev.	Std.
22	Mot.	Std.	Rev.	Std.	Std.	Diff.	Std.	Rev.	Std.	Rev.	Std.	Std.
23	Mot.	Std.	Rev.	Rev.	Std.	Diff.	Std.	Rev.	Rev.	Std.	Rev.	Rev.
24	Mot.	Std.	Rev.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Std.	Rev.	Std.
25	Mot.	Std.	Rev.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Rev.	Std.	Rev.
26	Mot.	Std.	Rev.	Std.	Rev.	Diff.	Rev.	Double Rev. —Std.	Std.	Std.	Rev.	Rev.
27	Mot.	Std.	Rev.	Rev.	Rev.	Diff.	Rev.	Double Rev. —Std.	Rev.	Rev.	Std.	Std.

Case III (a)—Machine operating as a *compound wound motor* before change (Standard Diagram Fig. 28). To continue operating as a *motor* after change, but under new conditions specified.

*28	Mot.	Std.	Std.	Std.	Std.	Cpd.	Std.	Std.	Std.	Std.	Std.	Std.
29	Mot.	Std.	Std.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Rev.	Rev.	Rev.
30	Mot.	Std.	Std.	Std.	Std.	Diff.	Std.	Rev.	Std.	Std.	Std.	Rev.
31	Mot.	Std.	Std.	Rev.	Std.	Diff.	Std.	Rev.	Rev.	Rev	Rev.	Std.
32	Mot.	Std.	Std.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Rev.	Rev.	Rev.
33	Mot.	Std.	Std.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Std.	Std.	Std.
34	Mot.	Std.	Std.	Std.	Rev.	Diff.	Rev.	Double Rev. —Std.	Std.	Rev.	Rev.	Std.
35	Mot.	Std.	Std.	Rev.	Rev.	Diff.	Rev.	Double Rev. —Std.	Rev.	Std.	Std.	Rev.
36	Mot.	Std.	Rev.	Std.	Std.	Cpd.	Std.	Std.	Std.	Rev.	Std.	Std.
37	Mot.	Std.	Rev.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Std.	Rev.	Rev.
38	Mot.	Std.	Rev.	Std.	Std.	Diff.	Std.	Rev.	Std.	Rev.	Std.	Rev.
39	Mot.	Std.	Rev.	Rev.	Std.	Diff.	Std.	Rev.	Rev.	Std.	Rev.	Std.
40	Mot.	Std.	Rev.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Std.	Rev.	Rev.
41	Mot.	Std.	Rev.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Rev.	Std.	Std.
42	Mot.	Std.	Rev.	Std.	Rev.	Diff.	Rev.	Double Rev. —Std.	Std.	Std.	Rev.	Std.
43	Mot.	Std.	Rev.	Rev.	Rev.	Diff.	Rev.	Double Rev. —Std.	Rev.	Rev.	Std.	Rev.

Case III (b)—Machine operating as a *differentially wound motor* before change. To continue operating as a *motor* after change, but under new conditions specified.

This case is same as Case III (a) except:—
(a) Under "Direction of Series Current" where "Std." is specified substitute "Rev." and vice versa, Figs. 29-43.
(b) Under "Series Field Leads" where "Std." is specified, substitute "Rev." and vice versa, Figs. 29-43.
(c) Under "Compound or Differential Series Field," substitute "Diff." in standard diagram, Fig. 28.

Case IV (a)—Machine operating as *compound wound motor* before change (Standard Diagram Fig. 44). To operate as a *generator* after change under conditions specified.

*44	Mot.	Std.	Std.	Std.	Std.	Cpd.	Std.	Std.	Std.	Std.	Std.	Std.
45	Gen.	Std.	Std.	Std.	Std.	Cpd.	Std.	Std.	Std.	Std.	Std.	Rev.
46	Gen.	Std.	Std.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Rev.	Rev.	Std.
47	Gen.	Std.	Std.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Rev.	Rev.	Std.
48	Gen.	Std.	Std.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Std.	Std.	Rev.
49	Gen.	Std.	Rev.	Std.	Std.	Cpd.	Std.	Std.	Std.	Rev.	Std.	Rev.
50	Gen.	Std.	Rev.	Rev.	Std.	Cpd.	Std.	Std.	Rev.	Std.	Rev.	Std.
51	Gen.	Std.	Rev.	Std.	Rev.	Cpd.	Rev.	Rev.	Std.	Std.	Rev.	Std.
52	Gen.	Std.	Rev.	Rev.	Rev.	Cpd.	Rev.	Rev.	Rev.	Rev.	Std.	Rev.

Case IV (b)—Machine operating as a *differentially wound motor* before change. To operate as a *generator* after change, under conditions specified.

This case is same as Case IV (a) except:—
(a) Under "Direction of Series Current" where "Std. is specified, substitute "Rev." and vice versa Figs. 45-52.
(b) Under "Series Field Leads" where "Std." is specified, substitute "Rev." and vice versa, Figs. 45-52.
(c) Under "Compound or Differential Series Field,' substitute "Diff." in standard diagram, Fig. 44.

*Standard diagrams for basis of comparison, showing wiring connections before changes are made to alter the conditions of operation.

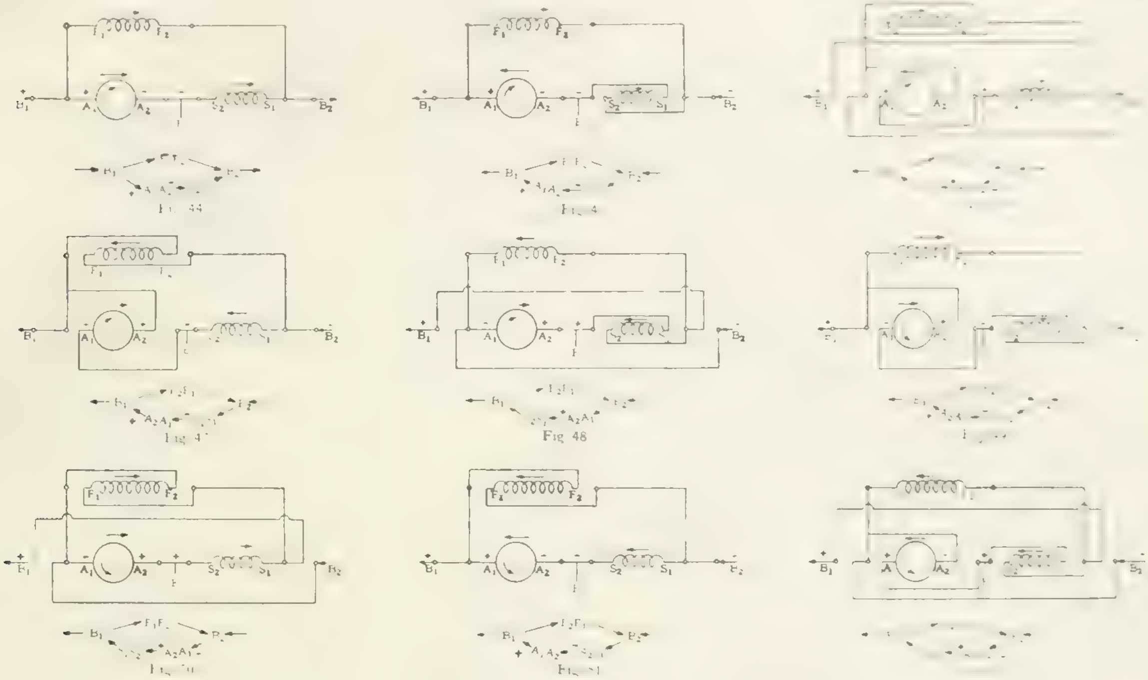
a—Actual interchange of leads for both armature and commutating pole windings, or
b—Rocking the brushes one pole in either direction for armature reversal and interchanging the leads of the commutating pole winding only.

Of the two methods, selection will be largely determined by two factors:—

Series field polarity.
Mechanical construction of the machine.

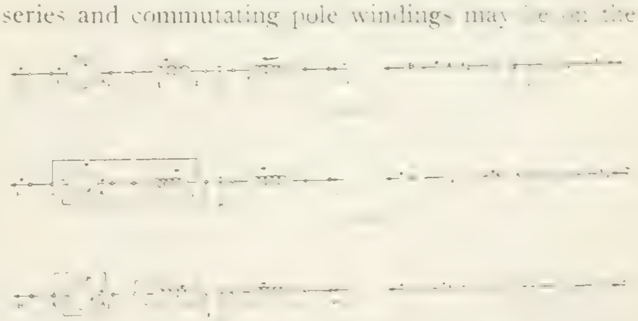
As indicated in Figs. 54 and 55 the first distinction between the two methods described above is that for the first case the commutating-pole winding is changed to the opposite side of the armature from the series-field winding, while for the second case the commutating-pole winding still remains on the same side of the armature as the series. This feature is of considerable importance. Due to the fact that the mechanical clearance between the series and commutating pole coils is often extremely small, it is always preferable to locate both these windings on the same side of the armature. Under this condition the difference of potential between them is only a few volts. If located on opposite sides of the armature, the maximum potential of the machine exists between the coils and accidental contact would be equivalent to a short-circuit, with disastrous results. In many cases therefore the equalizer polarity, by fixing the polarity of the series winding, also determines which of the two methods for reversal of the armature and commutating pole windings shall be employed. With respect to the individual reversal of both armature and commutating pole windings, mechanical conditions in certain types of machines prevent rocking the brushes a complete pole pitch; reversal of the leads in each set must therefore be effected by actual interchange of the leads.

As an example of the manner of making the diagrams applicable to commutating-pole machines, consider the same illustration used in explaining the construction of the diagrams (Fig. 10). Changes involved in that instance were reversal of main leads and reversal of armature leads. In order that the series and commutating pole windings may be on the same side of the armature, it is essential that the second method of reversal for armature and commutating pole windings (Fig. 55) be employed.



FIGS. 44-52—DIAGRAMS CORRESPONDING TO CASE IV(a) OF TABLE I

Fig. 44 is the same as Fig. 28 and is used in this case also as the basis of reference.



FIGS. 53-55—DIAGRAMS [illegible] FOR ARMATURE AND COMMUTATING [illegible]

Showing the two methods of reversing the two as a unit.

Opportunities for Engineers in Sales Work

S. L. Nicholson
Sales Manager,
Westinghouse Electric & Mfg. Company

VARIOUS classes of engineering services are required by a large electric manufacturing company. The research engineer delves into compositions of materials and theoretical considerations and must be of an analytical turn of mind. The designing engineer must be able to design apparatus and supplies to meet certain definite requirements at a minimum cost; that is, he must be able to design apparatus which can be sold at the regular market price and at a profit for the company. Engineers are also required for testing and supervising the erection of apparatus.

A comparatively new type of engineering presents just now a greater field of opportunity than almost any other; viz., the field of application engineering. The field of activity is almost unlimited, as it has to do with the application and uses of electricity in connection with practically all the ramifications of industry. The application engineer should have a knowledge of both electrical and mechanical engineering; he must understand what results are obtainable. He must be proficient in sales work from the standpoint of understanding commercial conditions. He must be responsible (considering one phase of the work) for the electrical development and laying out of power houses, transmission lines and railway work. He must be able to co-operate with the other engineers in making up plans and estimates of specific layouts and he must also be sufficiently commercial to interest bankers in his new projects. In another type of application engineering the engineer is responsible for the development of an industry, and in this case he must be also a process engineer; he must understand factory methods and be able to propose improvements by the use of electric power; he must be able to apply existing apparatus to the field conditions in such a manner as to produce a profit for the investor.

Another class of engineering is taken care of by the consulting engineer who must have a broad experience and should be an application engineer as well as somewhat of a designing engineer.

In order to apply engineering to sales work so that the relation between the two may be understood readily it will be well to outline the various classes of men engaged in an electric sales organization. The negotiation salesman is found largely in the central station or railway work. He has perhaps comparatively little knowledge of pure engineering theory (his plans can be worked up in detail by the application or designing engineer), but he must be of the promoter type, that is, he should be able to see opportunities for development in water-power sites, etc. Bearing in mind the community needs, he should be able to interest the bankers so that the undertaking can be properly financed, and he must be able to translate engineering terms into the language which non-technical men can understand. The old method of selling, via the stomach, has given away to service selling by the promoting engineer.

The electrical engineering salesman who is found in the railway, lighting and supply departments, must know the design of his apparatus in such a way as to be able to present to the customer the best arrangement of apparatus to suit his needs.

The application salesman is found principally in industrial and power work, and to a lesser degree in the illumination and railway fields.

The merchandising salesman has to do almost entirely with the merchandising of commodities through dealers, jobbers, etc. He must be familiar with price situations and methods of distribution and must be able to create a demand for his product. His work consists largely in creative salesmanship.

It will perhaps be advisable to outline some of the functions of the sales department. First, is the laying out of new central station plants and railway systems, which is a function of the negotiation and electrical engineering salesman. Consideration must be given to the capacity of stations, the size of generators, the requirements of transmission lines, and the conditions in railway service. This work requires a great deal of co-operation with consulting engineers. Next, is the revamping of old plants, in which the application engineer studies how to use the latest devices to increase output or to economize in operation so as to increase earning capacity. He must make friends and be able to create confidence by getting into close touch with the customer.

The application of motors to various industries requires a high type of engineering and provides a wide field of opportunity. Motors are sold for complete plants to increase output, to reduce cost or to better the product. To determine how to do these things is the study of the process application engineering salesman. There must also be an outlet for apparatus through the re-sale trade, such as to machine-tool builders, and the manufacturers of centrifugal pumps, elevators, etc., who purchase motors to be sold again. Since these buyers are mechanical rather than electrical engineers, the salesman must be both an electrical and mechanical engineer. Ten years ago the tool builders fought electric drive. Electrical salesmen showed that by strengthening the tool rest of an 18 inch lathe and applying an adjustable speed motor, the lathe could be sold for a higher price by basing the guarantees on the

amount of metal that could be cut in a given time. The wide range of speed control of electric motors became an important factor in enabling efficient use of high speed tool steel to be made. It became necessary to study torque conditions in order to determine the proper motor to apply. For example, in raising the head of a boring mill, where formerly a two horsepower motor was used, a three-quarter horse-power motor is now furnished and 300 percent full-load torque is required for short intervals of operation. The activity of these men in applying electrical equipment to complete plants and to the re-sale trade results in increasing the central station loads.

The services of a few electrical engineering salesmen are required in the sale of transformers, regulators, reactance coils, meters, etc., to central stations. Switchboard engineers, located in the larger sales offices, design switchboards for specific cases out in the field and send the specifications to the factory. Other salesmen study conditions for the application of heating devices for various industrial purposes.

The necessary qualifications of an application engineering salesman may be briefly indicated. He must be able to analyze conditions carefully from an engineering and economic standpoint and draw conclusions therefrom. In connection with the activities of the present application salemen, more mistakes are made on the mechanical side than on the electrical side. In applying motors it is necessary to decide whether they should be connected by belt, gear or chain to the device which they are to run, to determine the number of bearings needed, etc. The salesman must be able to analyze and draw conclusions so as to be able to present his case to the designing engineer in a clear concise manner, including details, so that the engineer will not have to go back for further information. He must also be able to present his case in a way that will be understood by the customer. He must not tell the textile man that his motor has high torque, but rather that it will throw the shuttle clear across at the first crack. In other words, he must translate electrical engineering jargon into ordinary textile mill English. He must have what the large majority of men lack, *initiative*. He must be able to see openings for electric motors in new fields and analyze them. For example, he must analyze a cement mill to find out whether electric motors can be installed, and how, together with all the details, and be able to determine whether the output can be increased, quality bettered and cost reduced; and must then find ways and means of getting the message to Garcia.

There are certain fundamental essentials for every salesman. He must be very enthusiastic and never discouraged. He must have confidence in himself, in his product, and in his Company. Some salesmen who think they know it all have proven weak-kneed when they strike a difficulty. The salesman must know how to present himself and his product. He must know how to get the signature at the psychological moment.

I have observed numerous college graduates and find that a great many of them are not very much good at first. The student should be awakened to an interest in his subject, and should also become interested in doing something outside of the class room which requires individual initiative. For example, he should be required to write a report on what is being done with respect to the application of motors to certain industries in the neighboring territory. The student should obtain a good foundation in fundamentals and be a good mathematician. Most students are being trained for the purpose of making a living. They should be shown how a certain formula is useful, for example, in building this or that kind of a bridge, thus awakening practical interest. They should use a slide rule. A man should go to college to get the right brain kinks, to think rightly and to reap the benefit of mixing with his fellowmen, as well as to acquire knowledge. The student should develop a keen sense of analysis and know how to express himself on his feet and to say what he thinks. He should be made to understand that, unless he can improve conditions, his work will be for nought. To improve industrial methods or conditions should be his mission in life.

To know how to think gives the right results in the long run. Of two boys, start one to college and one to work. The latter will get better pay at 22 years of age and can get results. He has mixed with laboring men but he does not know society nor how to present himself to a president or manager. At 35 the shop man has usually reached his limit: the other man passes him because he knows how to think.

College professors should study the various fields in which mechanical and electrical engineers should be located, so that they can give proper advice to their students. They should get outside men to come to the the college and discuss the fields of the future. Instead of merely hearing the boys recite they should get into human relations with them. Psychologists should sort the freshman on coming to school. The teachers should then get at the souls of the students and attempt to build men rather than to cram brains. I have a great admiration for teachers, as there is no calling so great as that of building men.

The Engineering Evolution of Electrical Apparatus—V

THE EVOLUTION OF THE TRANSFORMER

J. S. PECK
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The British Westinghouse Electrical & Mfg. Company, Ltd.

THE WRITER'S EXPERIENCE dates back to 1893, when as a student from college he began the study of transformer design in the laboratory of the old Westinghouse shops in Garrison Alley, Pittsburgh. At this time the general theory of transformer design was well known to a few Westinghouse engineers who, under the guidance of Mr. Chas. F. Scott, the electrician of the Company, had worked out curves giving losses in steel at various inductions and frequencies, who had developed formulae for determining the reactive e.m.f. and regulation at various power-factors, and who appreciated that precautions were necessary in order to prevent eddy currents in the conductors. With this knowledge available it is not strange that there are practically none of these "freak" designs to describe, which are usually left along the paths of progress to indicate in spectacular manner the state of the art at different periods. Great progress has been made, but the development has been a gradual one, due far more to improvements in materials and in mechanical construction, and to increased knowledge of high voltage phenomena, than to radical changes in electrical design.

TRANSFORMERS were first used in America for supplying lights, and in 1893 the largest standard size manufactured by the Westinghouse Company was 6¼ kilowatts, known as the 125 lighter or the No. 25, and it was about this time that the rating of transformers began to be specified in kilowatts. It is of interest here to note that at this period of the development the foreman of the winding department could give from memory the total turns, layers and turns per layer in primary and secondary windings of every transformer ever built by the Company, and could also describe in detail how each transformer was insulated. There were a few standard sizes of punchings, and the designer would work out the size of wire and number of turns, and leave the question of insulation to the foreman. Needless to say, there were frequent and emphatic differences of opinion as to the amount of wire which could be placed in a given opening.

FIG. 1 FIRST TRANSFORMER BUILT IN THIS COUNTRY
Constructed by Wm. Stanley, at Great Barrington, Mass.

SHAPE OF PUNCHINGS

In the original Westinghouse transformer a punching known as the B type was used. This was of the form shown in Fig. 2, and obviously involved a large amount of scrap in punching. To overcome this difficulty Mr. Scott had designed, about 1892, what was called the E plate which could be punched with practically no scrap. This design was used as a standard for many years, and its introduction made an enormous saving in the cost for steel. In punching the discs for armatures from square plates, the corners were thrown away. Here Mr. Scott proposed an F plate designed to use these corners to the greatest possible extent. But this scheme did not come into general use as the quality and thickness of the armature steel was not always the same as that required for transformers, and magnetic difficulties were encountered when the short arms of the plate did not butt closely. Plates of L shape were also used, but all types have been superseded except for small or special designs by the simple I plate.

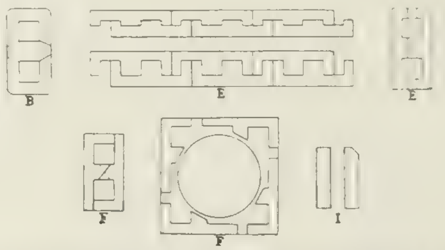

FIG. 2—OUTLINE OF B, E, F AND I TRANSFORMER PLATES

QUALITY OF STEEL

From the earliest days of transformer manufacture the question of the quality and treatment of the steel punchings was a serious one. The best thickness of plate, the proper chemical analysis and heat treatment, and the best method of insulating the laminations were all matters to be decided. About 1893 or 1894 the matter was receiving most careful study by the Westinghouse engineers. Chemical analysis was naturally one of the first characteristics to be investigated. A sample of steel which gave excellent results as to losses was analyzed and steel purchased

according to this specification. The results were conflicting and confusing, and after an immense amount of work it was decided that there were other unknown factors of even more importance. Annealing was tried

FIG. 3—100 KW NIAGARA FALLS TRANSFORMER
One of the first water-cooled transformers built.

under all kinds of conditions, slow heating and rapid heating, slow cooling and rapid cooling, long heating and short heating, and even magnetizing the iron while undergoing the treatment. Many times the investigators felt sure they had solved the problem, but the quality of the steel showed in general little improvement. At one time it was thought that Bessemer steel of a certain analysis, treated in a certain manner, offered the solution, but it was soon found that this material aged rapidly after being put into service, and a long series of investigations was undertaken in connection with the aging problem. For a long time test samples were taken from practically every shipment of steel received and subjected to long time aging tests in addition to the usual tests for losses. It was soon found that aging was due to temperature and not to magnetic action and that some materials were practically constant at the maximum working temper-

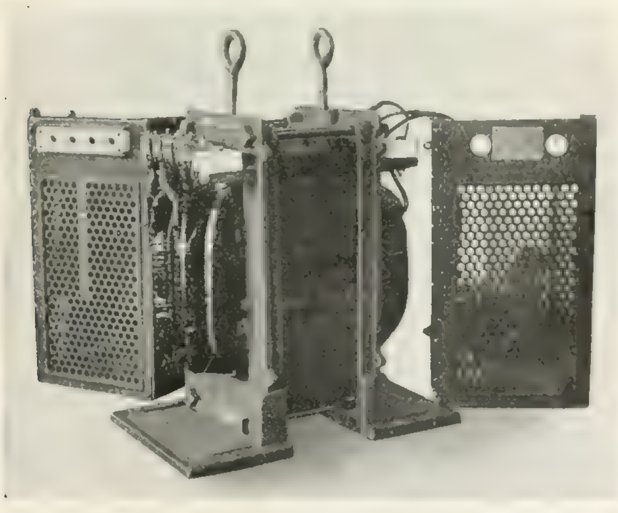

FIG. 4—EARLY SHELL-TYPE TRANSFORMER

ature, while others would age if left in the warm furnace room. An immense amount of time and money was spent in searching for the method of producing the best grade of steel, but no very satisfactory solution was reached, until the discovery of the so-called alloy steel, and even today there is sufficient variation in quality to indicate that finality has not been reached.

In 1893 the success of the San Bernardino 10 000 volt transformers and the proposed electrical development at Niagara Falls made it evident that transformers for higher voltages and larger capacities than any built before would soon be required, and soon after this date it was decided to build an experimental transformer of a size much larger than any attempted before, viz., 100 kilowatts. The advantages of oil, both as a cooling and an insulating medium, were fully recognized, and it was decided to make this transformer oil cooled, and as it was not considered feasible to make a transformer of this size self-cooling, it was decided to put it in a boiler iron case and cool it by circulating water. It is believed that this was the first transformer of this now well known type. The tests were very satisfactory and a large amount of very valuable information was obtained.

INSULATION

With the advent of the larger transformer wound for higher voltages than those in common use, it was

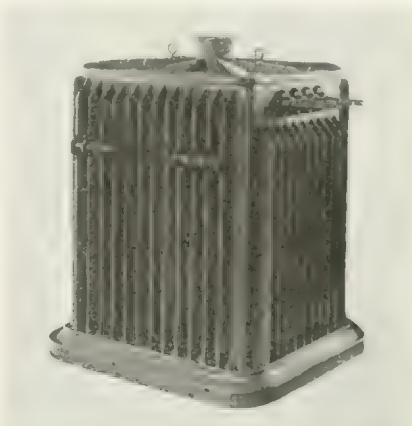

FIG. 5—ORIGINAL TYPE OF TANK FOR OIL INSULATED, SELF-COOLED TRANSFORMERS

obvious that the question of insulation could no longer be left to the shop but that it must be worked out and specified with as great care as was the purely electrical design. As little or nothing was known as to the insulating properties of most of the materials available, especially at high voltages, it was necessary to begin investigation along these lines, and thus the "Insulation Expert" was started on his career. The explorations in this almost unknown field were entrusted to Mr. C. E. Skinner, who was ably assisted by Mr. P. H. Thomas, and the subject of transformer insulation soon began to take on a scientific form, in fact so "scientific" did the insulation specifications become that great difficulty was found in getting the "shop" to follow them. While this difficulty may exist to-day in a minor degree, simplification and standardization have practically eliminated it. The subject of the development of insulation materials and methods is one which deserves a complete story in itself, but

it would not be right to pass it over in this article without mentioning the question of oil.

When the first oil insulated transformers were built it was necessary to choose a suitable oil from those then placed on the market for other purposes, and one was chosen which showed good insulating

FIG. 6—EARLY SELF-COOLED BOILER IRON TANK

properties, which had low viscosity, and which could be obtained at a reasonable price. This oil gave excellent results, and is still employed to a considerable extent. The objection to it was its low flash point and, as the business developed, the oil refiners were called upon to produce an oil having a higher flash

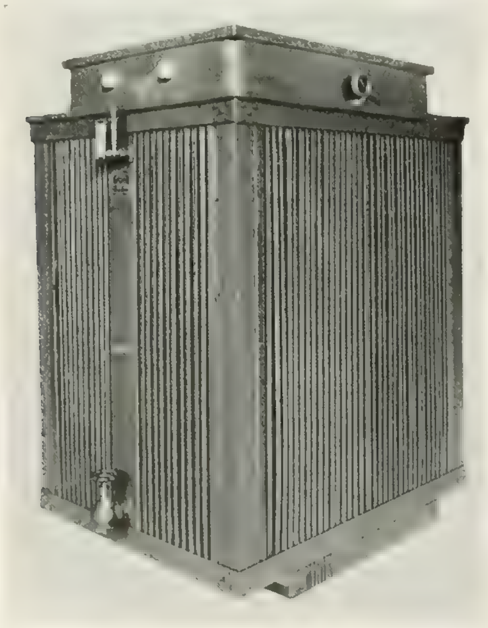

FIG. 7—EARLY STANDARD TERNEPLATE TANK

test while retaining the other desirable qualities. Several different grades were produced and in general gave satisfaction. During the latter part of the 90's it was found that with certain grades of oil a deposit was formed on the cooling coils of water-cooled transformers and in the vent ducts of certain large condensers used for lightning protection. An extensive investigation was begun at once in which different qualities of oil were subjected to the various influences which it was thought might produce the deposit. These tests soon demonstrated that heat was the cause of the deposit, and that voltage stresses had nothing to do with the phenomena beyond causing the particles to line up in certain ways. It was also found that some grades of oil showed far greater deposits than others. This question of deposit appeared to be a new problem to oil refiners, but they took up the question and after struggling with it for years have at last produced oils which are practically free from deposit at any reasonable temperature.

In carrying out his investigations on protective apparatus for transformers and generators, Mr. Thomas worked out a theory showing why the end windings of transformers, generators, etc., broke down more frequently than other parts of the windings, and

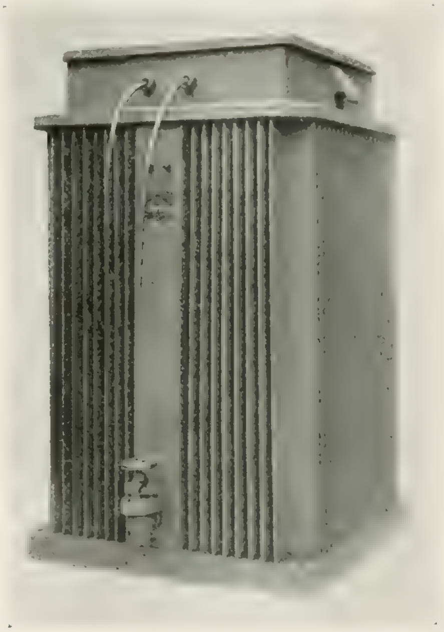

FIG. 8—MODERN STANDARD CAST-IN TYPE OF SHEET STEEL TANK FOR SELF COOLING TRANSFORMERS

his paper in 1902 gave most valuable data, which has been confirmed and "rediscovered" by many investigators since. This paper showed clearly the utility of choke coils in the leads of high voltage electrical apparatus, or the necessity of increasing the insulation between the end turns, as well as the advisability of avoiding certain switching operations.

TRANSFORMER TANKS

In 1896 a large order was received for 10 000 volt oil insulated transformers of various sizes, the largest being 100 kilowatts. These were placed in cast iron cases with ribs cast on the inside and outside. The larger cases were made in six pieces—top, bottom and four sides, as shown in Fig. 4. The four side pieces were bolted together and then bolted to the bottom casting, all joints being machined and fitted with lead gaskets. This gave a very heavy and ex-

pensive case, and great difficulty was experienced in making the joints tight. Experiments indicated that the inside ribs were of no value, and they were omitted on later transformers.

It soon became apparent that transformers of a capacity much greater than 100 kilowatts would be required, and as water cooling could not always be obtained, it was evident that some form of self-cooling case was necessary, which could be built at reasonable cost and which would present a very large amount of cooling surface to the air. This demand led to the development of the sheet steel case. The first cases of this type were built of terneplate with plain sides. Around the interior, close to the outer walls, was arranged a series of rectangular tubes. The lower end of each tube stuck through the bottom of the case and was soldered to it, while the upper end was open and came above the oil level. Thus these tubes constituted a series of chimneys or flues through which the air could pass. A considerable number of these tanks were built for transformers of 375 kilowatts maximum capacity, and they were much lighter and cheaper than the cast iron cases. It was discovered, however, that a tank with the sides corrugated and open to the air was much cheaper to build, easier to repair and, surface for surface, gave better cooling than those with the internal chimneys, and this type was soon adopted as standard. The construction of these tanks was quite simple. The terneplate sheets for the sides were corrugated in a banding machine, then riveted as shown in Fig. 7, and soldered together. The four sides were then set into a channel in the bottom, also made of terneplate, and this channel was flooded with solder. The whole case was then mounted in an angle iron framework and provided with cast or sheet iron covers. Large numbers of these tanks were manufactured in capacities up to 500 or 600 kilowatts. They were light, strong, and reasonably cheap to manufacture. It was attempted to reduce the cost of the tanks by using a folded seam down the sides instead of a riveted one. This proved a costly experiment, for after being in service for a few months the tank would begin to leak due to the breaking of the seam by the mechanical forces set up by the expansion of the metal due to alternate heating and cooling, and it was necessary to revert to the riveted seam. This type of case gave general satisfaction, until a fire occurred in a large station containing a dozen or more large transformers. The heat melted the solder in the seams, the oil ran out on the floor and added to the flames, and the destruction of the whole station was narrowly averted. This fire demonstrated the danger of using soldered joints in a case containing oil, and designers at once began to consider other types.

In 1903 or 1904 it occurred to the writer that it should be possible to make a boiler iron tank with external cooling tubes, one end of each tube being riveted into the tank near the top and the

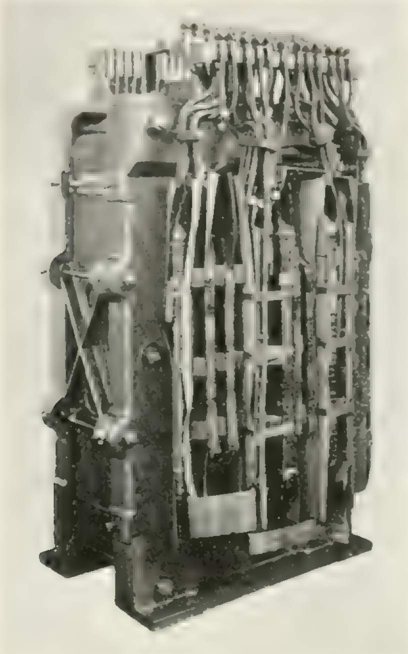

FIG. 9—375 K.V.A. HEAVY-CURRENT TRANSFORMER FOR NIAGARA FALLS

FIG. 10—BOILER STEEL TANK FOR TRANSFORMER SHOWN IN FIG. 9

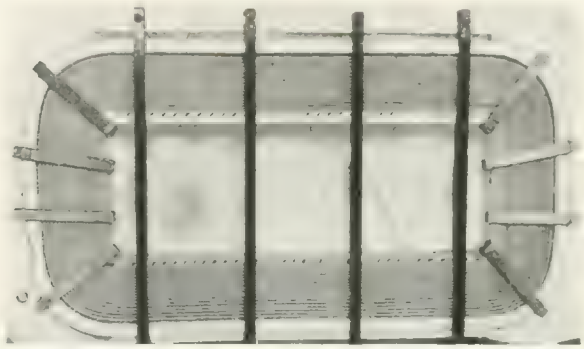

FIG. 11—MODERN ONE-TURN-PER-LAYER HIGH-TENSION COIL, WITH EXTRA INSULATION BETWEEN END TURNS

other end near the bottom so that the hot oil would flow from the top of the tank through the tubes and reenter the tank at the bottom. A small tank was built up of terneplate in order to test the efficiency of the cooling tubes, but apparently on account of the small dimensions of the case the anticipated results were not obtained, and the construction was abandoned. However, at a later date it was taken up again on a larger scale and has proved a great success. Fortunately the perfection of the method for welding sheet steel plates by means of the oxy-acetylene flame made it possible to build sheet metal tanks without the use of solder. After the sides are formed into shape and welded, the top and bottom are cast on, as shown in Fig. 8. This construction makes a thoroughly sound job, and on account of the saving in solder the welded tank is considerably cheaper than the soldered one.

While the development of the self-cooling tank was progressing, the water-cooled transformer was being built in larger and larger sizes. The construction was similar to that adopted on the large experimental transformer built in 1894, i. e., the tanks were of boiler plate and the cooling done by means of water coils placed below the surface of the oil. In some large plants the oil was cooled by pumping it through coils of pipe located in a water tank placed external to the transformer. The advantages claimed for this method are that better cooling is obtained due to the forced circulation of the oil and that any leak in the cooling coils will cause oil to escape into the water and not water into the oil, but the greater simplicity

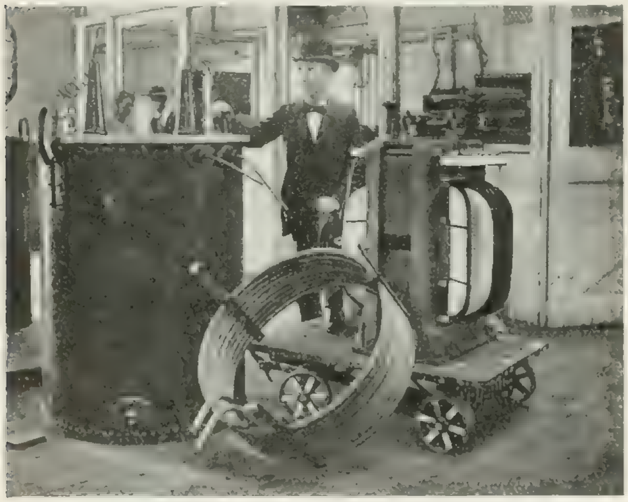

FIG. 12—EARLY 75 KW HIGH-TENSION WATER-COOLED TRANSFORMER

Having pancake coils of several turns per layer, and wooden high-tension terminal bushing.

of the former method has caused it to be adopted in the great majority of plants.

AIR BLAST TRANSFORMERS

One of the first of the large fields for the transformer was that of supplying power for rotary converters, and these machines were often located in the most congested portions of large cities. For such places the presence of the large quantities of oil required for oil-cooled transformers constituted so great a fire risk that there was great hesitancy over the use of this type, and largely to meet this condition the air-blast transformer was developed. This transformer is placed above a chamber or duct in which the air is

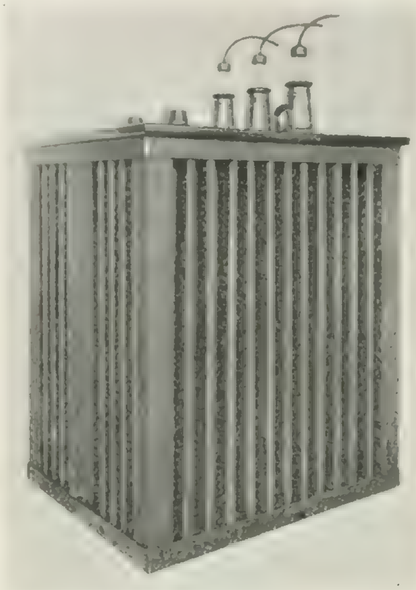

FIG. 13—TRANSFORMER WITH WOODEN TERMINAL BUSHING LINED WITH GLASS

maintained at a pressure slightly above atmosphere by means of a motor-driven fan. Ducts are arranged between the windings so that very effective cooling is obtained, but on account of the larger ducts, the greater clearances and the heavier insulation required by this type as compared with the oil cooled type, its efficiency is somewhat lower. Also this type of transformer is not well suited to stations where there are no attendants, as any failure in the air supply would soon cause the transformer to overheat and burn out. Thus its use has been limited principally to rotary converter sub-stations where there is constant supervision during working hours. The General Electric Company was first in the field with the air blast transformer, and there were many discussions as to the relative merits and demerits of air-blast and oil-cooled transformers, but gradually the field for which each type is best suited has become clearly defined, and all transformer manufacturers are prepared to build either type. In a few cases a combined oil cooling and air blast transformer has been used on large high voltage transformers when water for cooling is not available.

INCREASE IN VOLTAGE

Reference has already been made to the 10 000 volt transformers constructed in 1896. These were the first transformers built by the Westinghouse Company for so high a voltage for commercial service, but within a year of the shipment of these transformers others were going through the shop wound for 20 000 volts, and in a very short time orders were taken for

some large 50 000 volt transformers. These transformers were all of the shell type with flat or "pancake" coils and with several turns per layer. Some troubles were experienced, but when the general ignorance regarding high voltage strains and insulation

FIG. 14—TRANSFORMER WITH TREATED PAPER TERMINAL IN A PORCELAIN BUSHING

material is considered, the wonder is that troubles were not more frequent than was really the case. It may be stated, however, that the high voltage shell-type transformer did not become a thoroughly safe piece of apparatus until the introduction of the strap coil winding with one turn per layer and with both insulation and copper thoroughly ventilated.

While the advance to 50 000 or 60 000 volts was a rapid one, progress halted here, due largely to the fact that the limit of the pin type insulators had been reached, but with the introduction of the suspension type insulator, progress began again, and voltages for 80 000 and 100 000 were soon common and, as is well known, 150 000 volts is now in use and there seem to be no limiting features in the design of the transformer to prevent the use of much higher voltages. In the first high voltage transformers, wood or porcelain bushings were used for bringing out the terminals, but as the voltages increased the wood bushing was lined with a very heavy glass tube. Then long tubes of treated paper were adopted and these were finally replaced by the condenser type of terminal that has been fully described and is so well known that it requires no further description here.* In the meantime the General Electric Company had developed an oil filled terminal. This terminal is built up of a series of short cylinders separated by radial discs which increase the creepage surface. These cylinders and discs taper gradually from the flange towards the ends. The terminal depends principally upon the oil with which it is filled for its insulation.

SHORT-CIRCUIT STRESSES

In the first large transformers no attempt was made to brace the windings mechanically, as it was not appreciated that the repulsive forces between primary and secondary windings would be sufficient to cause distortion. This matter was brought out forcibly by a 200 kilowatt transformer returned from Niagara Falls about 1898. The low tension windings were of very heavy square wire and located partly on the outside of and partly between the primary coils. thus:—L H H L L H H L. Both ends of both outside coils were bent around at right angles to their original position and driven hard up against the end frames. It

FIG. 15—THE FIRST 110 000 VOLT TRANSFORMER

Built for the Grand Rapids Muskegon Power Company in 1908. The terminal consists of three concentric fiber tubes of different length, set in a bushing of cement, impregnated with paraffine

looked as though they had been deliberately driven over with a sledge hammer. When the cause for this trouble was ascertained, steps were taken to prevent it

*See "Condenser Type Terminals," by A. B. Reynders, in the JOURNAL for Oct., 1910, p. 766; and "The Condenser Terminal," by Chas. Fortescue and J. E. Mateer, in the JOURNAL for Aug., 1913, p. 718.

in the future, but so enormous were the forces involved that several attempts were made before a construction was evolved which would prevent distortion of the windings under the most severe possible conditions, i. e., with sufficient generator capacity to maintain full voltage across the primary with a direct short-circuit across the secondary terminals. The great rigidity of the coil support on modern large transformers gives some idea of the magnitude of the stresses involved, for the design of these supports is the outcome of costly experience. With the core type of construction it was thought that where the windings were circular and concentric the coils should be able to stand short-circuit stresses with very little bracing, as the principal forces are in a radial direction, but the way in which these windings were actually crumpled up and twisted out of shape when short-circuited across their terminals indicated that there were enormous forces acting in unexpected directions, and that the strongest possible bracing was required in an axial direction.

FIG. 16—105 000 VOLT TRANSFORMER WITH MODERN CONDENSER TERMINALS

THE DELTA-STAR CONNECTION

When transformers were first used for supplying three-phase circuits there was considerable doubt as to whether the windings should be connected in star or delta. The former required fewer turns in the winding and was somewhat cheaper .to wind and insulate, particularly when the neutral point was earthed, while the latter made it possible to supply three-phase current on two transformers connected in *V* in the event of one being disabled. A rather curious case occurred in one of the early railway installations, where the transformers were connected in star on both windings, which demonstrated clearly the danger of this connection. The sequence of events was as follows:—

a—Transformer No. 1 burned out and was replaced by a spare unit No. 1a.
b—Transformer No. 2 burned out and was replaced by a spare unit No. 2a.
c—Transformer No. 1a burned out.

Upon investigation it was found that transformer No. 3 had been short-circuited all the time, thus subjecting Nos. 1 and 2 to nearly double voltage, and naturally they had burned out. Apparently the attendant had failed at first to notice that transformer No. 3 was cold and the others hot.

With the star-to-star connection there is a triple harmonic pulsation in the e.m.f. between neutral and line which will set up inductive disturbances in neighboring telephone lines if the neutral point is earthed. Three-phase shell-type transformers are not essentially different from groups of three single-phase transformers in this respect. Three-phase transformers of the core type have interlinked magnetic circuits and for this reason the third harmonic is practically absent so that the star-to-star connection for such transformers is sometimes permissible.

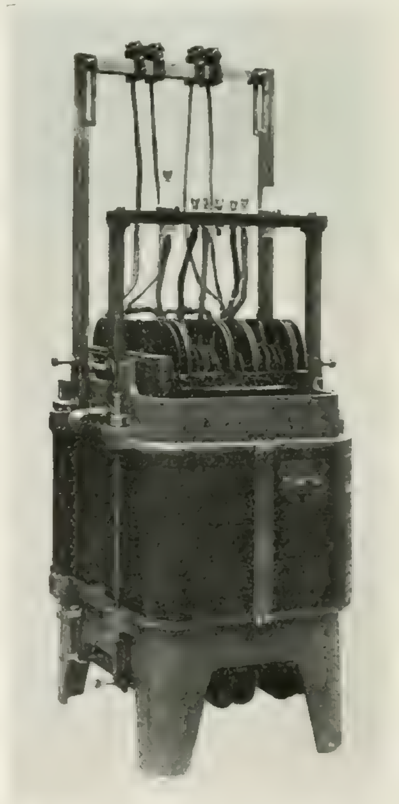

FIG. 17—MODERN TRANSFORMER WINDING

Showing rigid bracing of coil ends. Heavy impregnated timbers, faced with fiber or fuller-board, are pressed against the coil ends by the screws shown at both top and bottom on each side of the transformer.

Present American practice is in favor of the star connection on the high-tension side with a delta connected low-tension for transmission systems of 60 000

volts or above. This is for the reason that a transformer wound for star voltage or 58 percent of the line voltage requires less insulation and the coils themselves are more rugged, due to the larger conductors in the coils. With these advantages there is also some gain in efficiency and some saving in cost. The star connection permits earthing the neutral at any time it proves desirable while with the delta connection the neutral point is not accessible. For transmission systems below 60 000 volts either delta-to-delta or delta-to-star step-up transformers are used depending upon service conditions. In small installations where the cost of a spare transformer is a large proportion of the total investment, the delta-to-delta connection may be preferable, as operation can be continued, in case one transformer becomes disabled, with two of the three units operating in open delta.

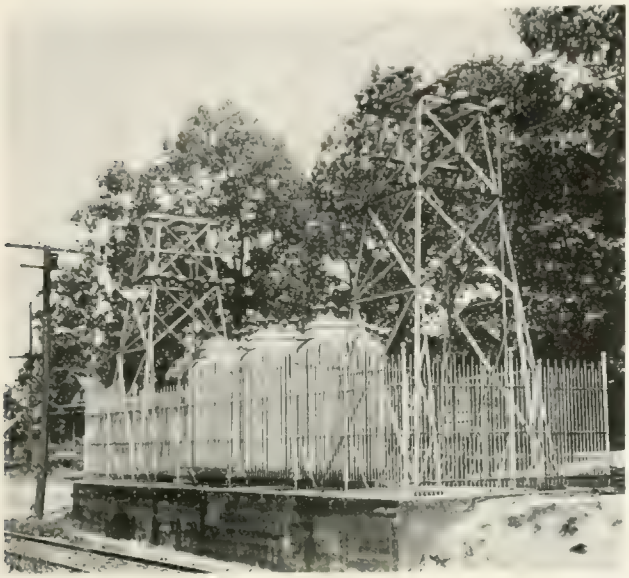

FIG. 18—AN OUT-DOOR SUB-STATION OF 1 000 K.V.A. TUBULAR-TYPE SELF-COOLED TRANSFORMERS

SHELL AND CORE TYPE

In the earlier days the Westinghouse Company manufactured the shell type of transformer almost exclusively, but today, with the broadening out of the field and the higher operating voltages, the core type is considered with equal favor and is largely used for small capacity transformers to operate on high-voltage transmission systems. It is also used for shunt transformers for measuring instruments and high-voltage testing transformers, etc. For these cases it is easier to insulate than the shell type and so has come into general use for this class of work. For higher voltages, that is 4 400 to 22 000 volts, the Westinghouse Company uses the core type. European manufacturers use the core type almost exclusively.

OUTDOOR TRANSFORMER STATIONS

The successful operation of the early outdoor transformer stations has led to the quite common use of high voltage transformers and switching equipment out of doors in the United States. Saving the cost of the building required to house the equipment is naturally the incentive for such stations and the development of outlet leads and bushings as well as switching apparatus that can be used successfully in all extremes of weather has made them possible. Oil insulated transformers of the self-cooling type are mainly used for this purpose, although oil-insulated water-cooled transformers have also been used successfully. It is necessary with the latter to protect the water cooling system against the freezing of the water during periods of cold weather. There are now many systems operating with voltages as high as 110 000 volts which make use of outdoor transformer stations. A bank of three of the tubular type self-cooled transformers used out doors is shown in Fig. 18. These transformers form part of the Georgia Railway & Power Company's system, whose main transmission is at 110 000 volts. These particular transformers operate in delta on a 22 000 volt circuit stepping down to 11 000 volts. They are rated at 1 000 k.v.a. each, making a sub-station of 3 000 k.v.a. output. It is interesting to note that the nearest station attendant is about two miles away. The economy in placing these transformers out doors with no building overhead is very apparent. American manufacturers have developed outdoor sub-stations of small capacity which are being used quite generally for the purpose of supplying moderate quantities of power along the route of a high tension transmission system. They are made up of standard transformers, switches and lightning equipment, mounted on a steel framework.

FIG. 19—AN OUTDOOR INSTALLATION [illegible] SELF-COOLED TRANSFORMERS

Figure 19 [illegible] switching equipment and lightning arresters.

Characteristic Curves of the Induction Motor

C. A. M. Weber

THE CHARACTERISTIC CURVES of both the squirrel-cage and the wound-secondary induction motor are frequently worked out theoretically, but it is seldom that such curves are plotted from actual test results. The curves presented herewith were plotted from data secured on a test run to determine the characteristics of a small induction motor under extreme operating conditions of torque and speed, and provide facilities for a more complete observation of the performance of the motor than is ordinarily possible from actual test data.

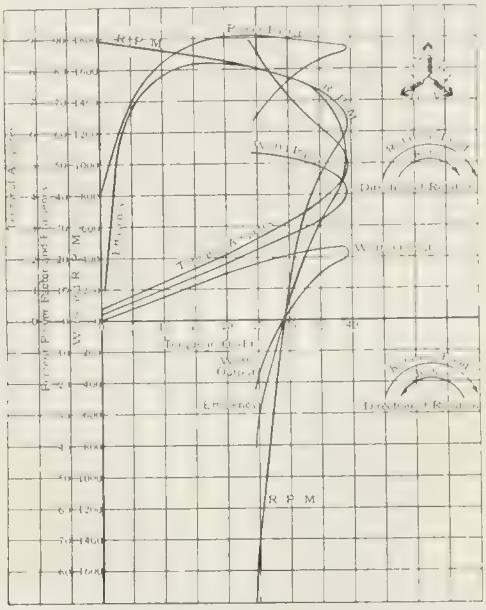

FIG. 1—CHARACTERISTIC CURVES OF A THREE-PHASE SQUIRREL-CAGE INDUCTION MOTOR

Taken from actual test over the entire range from rated speed through zero to full speed in the opposite direction.

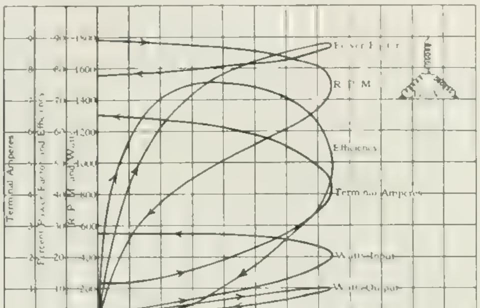

FIG. 2—TEST CURVES OF A THREE-PHASE SQUIRREL-CAGE MOTOR, OPERATING AS A SINGLE-PHASE MOTOR WITHOUT STARTING WINDINGS

The voltage, as indicated, was impressed across two legs of the star-connected winding. The arrows on the curves are in accordance with the direction in which the test progressed; that is, from no load to locked rotor.

POLYPHASE SQUIRREL-CAGE CHARACTERISTICS

Fig. 1 represents the test results obtained on a one horse-power, three-phase, 60-cycle, four-pole, 220-volt, star-connected squirrel-cage induction motor run on 110 volts. The object of running on half voltage was to reduce the effect of heating, especially when taking readings beyond the pull-out point of the motor. To further reduce the effect of heating, a fan was placed so as to blow air over and through the windings during the test.

Readings were taken for each of the curves of Fig. 1 over the range indicated, all values above the point of zero speed being determined by loading the motor with a shunt generator, and all values below that point by driving the secondary of the induction motor against the rotating field by means of a shunt motor; readings being taken of volts and amperes for both field and armature of the latter over the speed range covered. These latter readings were then duplicated with a Prony brake on the shunt motor, determining the values of torque over the same range of speed.

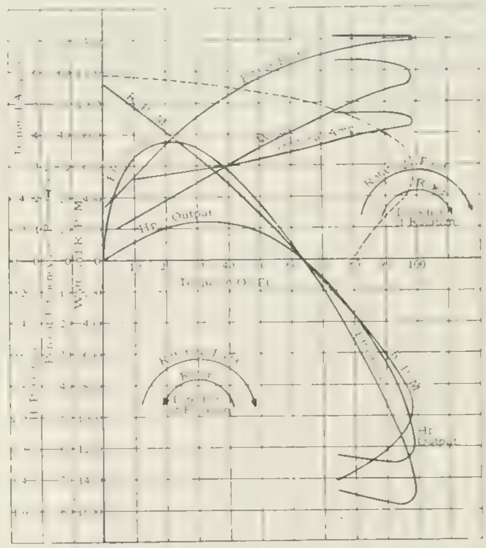

FIG. 3—CHARACTERISTIC CURVES OF A THREE-PHASE WOUND-SECONDARY MOTOR WITH EXTERNAL RESISTANCE

The dotted curve indicates for comparison the speed-torque curve of the motor with short-circuited secondary.

SINGLE-PHASE SQUIRREL-CAGE CHARACTERISTICS

The second test, the results of which are given in Fig. 2, was run on the same motor as used in the first, except that 110 volts was impressed across two legs of the star-connected winding, thus giving approximately the usual single-phase winding. The values for these curves were also obtained by loading with a shunt generator. It is impossible to secure negative readings on a single-phase motor, since the rotation of the field is always in the direction of rotation of the rotor and there is no rotating field when the rotor is at a standstill; hence there is no starting torque.

CHARACTERISTICS WITH VARIABLE RESISTANCE SECONDARY

In the third case a one-half horse-power, three-phase, 60-cycle, 220-volt, six-pole, star-connected in-

duction motor with wound secondary was connected to a normal voltage circuit with external resistance in the secondary circuit and a brake test was made up to the point of locked torque. Beyond this point the values were obtained as in the first test by running the motor against the rotation of its field, as indicated in Fig. 3, in which are plotted the complete test results.

These sets of curves covering the various factors in the motor circuit, very clearly establish the behavior of an induction motor under almost any possible condition of operation and are of particular interest in that they are the result of actual tests. They are, of course, on that account subject to the possibility of slight inaccuracies due to personal errors in observation and in instrument calibration, as would be expected in tests of this nature where readings must be taken with all possible expediency and dispatch.

Induction Motors for Varying Speed Service

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THE VERY GENERAL adoption of alternating-current distribution has led to the use of large numbers of polyphase induction motors for many and varied industrial applications. And with the ever increasing numbers of this type of motor being put into service there arise here and there instances of their being used for work for which their inherent characteristics render them unsuitable. Particularly is this the case where motors are intended for varying speed service. Hence the need that those wishing to use varying speed induction motors have a clear idea of their characteristics in order to determine their suitability for the particular application. The type of variable speed induction motor in most common use is that having a wound rotor or secondary, the speed being varied by means of a resistance inserted in the secondary circuit. This type only will be dealt with in this article.

WHEN CONSIDERING an induction motor for varying speed work the first point to be determined is whether its characteristics are such that it will be able to perform the required service in a satisfactory manner. If the service is such that an induction motor cannot do the work as it should be done, and alternating-current service only is available, it will be found more satisfactory in the end to use a direct-current motor together with the necessary motor-generator set. Even where the characteristics of an induction motor render it suitable, a careful analysis of the cost of power and the capital charges on the necessary apparatus may result in a decision unfavorable to the induction motor, due to its comparatively low efficiency (with its control resistance) when running at less than full speed.

In order to understand the operation of a varying speed motor, it is necessary to have a clear idea of the meaning of torque, and of the connection between horse-power, torque and speed. By the torque of a motor is meant the turning effort developed. The torque at any given speed determines the horse-power developed at that speed, the horse-power being proportional both to the speed and to the torque. Thus the horse-power, expressed in percent of full load, is the product of the speed, in percent of full speed, and of the torque, in percent of full-load torque (i.e. the torque, which at full speed will develop full load.)

The torque developed by a motor is always equal to the torque required to overcome the friction of the motor itself, together with the external torque required by the load, and a motor will always tend to a steady condition of torque and speed such that the portion of the torque developed, which is available for work external to the motor, will be equal to the torque required from the motor. That is to say, the torque exerted at any time by a motor will depend upon the torque required from the motor, and not upon the motor itself, or upon any adjustment of the control apparatus.

The operation of a varying speed induction motor is very similar to that of a direct-current motor, the speed of which is varied by armature control. The speed regulation of a direct-current motor, when used in this way, is very poor. Thus, when considering the adaptability of induction motors for varying speed work, it should be remembered that they have very poor speed regulation, i. e., on any notch of the control apparatus, the variation of speed with torque is large, and is larger, the larger the speed reduction required. Hence, an induction motor should not be used for varying speed work, where, while running on any one notch of the controller, the speed is required to remain constant, unless the torque demanded from the motor will also remain practically constant.

Several speed-torque curves of a six pole, 25 cycle induction motor are given in Fig. 1. Curve I shows the curve with the rotor short-circuited. The decrease in speed from no load to full load is 20 revolutions, the full load speed being 480 r.p.m. That is to say, the slip of the motor is $20 \div 500$, or four percent. The decrease in speed for any given value of torque will vary directly with the resistance of the rotor circuit. Thus, if external resistance is inserted so that the total resistance in the rotor circuit is five times the resistance of the rotor when short-circuited, the decrease in speed from no load to full load will be 5×20, or 100 revolutions, and the slip will be 20 percent. Hence, since at any given value of torque the decrease in speed below synchronous speed is directly proportional to the total resistance in the rotor circuit, by varying the external resistance by means

of a controller, various speed-torque curves may be obtained such as those shown corresponding to the different points on the controller. Curve II is the speed-torque curve corresponding to a total resistance of the rotor circuit equal to five times the resistance of the short-circuited rotor, and curves III, IV, and V are speed-torque curves with larger values of rotor resistance. It should be particularly noted that on any speed-torque curve there is one and only one speed corresponding to any value of torque; and, conversely, when running on a given notch of the controller, a given speed will be obtained only when the torque required from the motor is the same as that value of torque, which, on the given speed-torque curve, corresponds to the desired speed. Thus it would be possible to obtain a speed of 350 r.p.m. when operating under the conditions of curve V with a torque equal to 15 percent of full-load torque; of curve IV with torque equal to 30 percent of full-load torque; of curve III with torque equal to 60 percent of full-load torque; and of curve II with torque equal to 150 percent of full-load torque. Also, if 40 per-

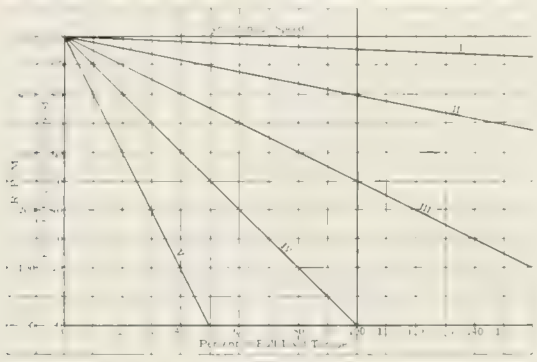

FIG. 1—SPEED-TORQUE CURVES OF A WOUND-SECONDARY INDUCTION MOTOR

Showing the effect of varying amounts of external secondary resistance. The curves are drawn as straight lines for comparison. However, for a motor with good pull-out torque, the downward droop of the speed-torque curves is so small within the range of torque shown that the difference is practically negligible.

cent of full-load torque is required from the motor; when running under the conditions of curve V the speed will be 100 r.p.m.; of curve IV, 300 r.p.m.; of curve III, 400 r.p.m.; of curve II, 460 r.p.m.; and with the rotor short-circuited, as per curve I, about 490 r.p.m.

From the above it is plain that, when running on any notch of the controller, the speed will vary as the torque required from the motor, the increase in slip being proportional to the torque. Moreover, the higher the resistance of the rotor circuit, the greater will be the decrease in speed below synchronous speed corresponding to any given value of torque. In other words, the larger the rotor resistance the greater will be the slope of the speed-torque curve, and hence the greater will be the variation of speed with torque. With the motor running as per curve I, with short-circuited rotor, the speed regulation will be good, the increase from the full-load speed of 480 r.p.m. to the no-load speed of 500 r.p.m. being 20 revolutions, corresponding to a speed regulation of $\frac{20}{480} = 4.2$ percent. Consequently, if, with short-circuited rotor, the torque should decrease from full load to one half that value, the increase in speed would be only approximately 10 revolutions. But, when running on the notch of the controller, corresponding to speed-torque curve III, which give full-load torque at one half synchronous speed, the speed regulation will be 100 percent, since the increase in speed from full load to no load is equal to full-load speed. And, should the torque vary from full-load torque to say one half of full-load torque, the speed will increase from 250 r.p.m. to 375 r.p.m. Thus, except when running with rotor short-circuited, the speed regulation of an induction motor is poor; and on any point of the controller it is worse the greater the speed reduction obtained.

When considering the variation of speed it is convenient to think in terms of torque rather than horse-power, but it might be well to notice the actual power output corresponding to any point on a speed-torque curve. Thus, when running as per curve III with full-load torque at one-half synchronous speed, the output will be approximately one-half full-load output expressed in horse-power. When running as per curve IV with 60 percent of full-load torque at 40 percent of synchronous speed, the output will be approximately 24 percent of full-load output expressed in horse-power.

The efficiency of a varying-speed induction motor and its control resistance can be easily determined at any value of torque and speed, if the efficiency curve for the motor, running with short-circuited rotor, is known. If E_1 = the efficiency of the motor and control apparatus at torque T and slip S_1 and it is desired to know the efficiency E_2 at torque T and slip S_2, then

$$E_2 = E_1 \frac{1 - S_2}{1 - S_1}$$

For example if the motor at torque T has 88 percent efficiency and five percent slip, at half speed (50 percent slip) and torque T the efficiency =

$$88 \times \frac{50}{95} = 46.3 \text{ percent.}$$

The number of applications of varying speed motors is so large that it would be practically impossible to discuss the suitability of induction motors for all the possible kinds of service. But from the above notes on their operation, the person desiring to use them, and hence having a thorough knowledge of the requirements of the particular application under consideration, should be able to decide whether or not they can be used. It cannot be emphasized too strongly that an attempt to use these motors for work for which they are not suited should not be made. The legitimate field of induction motors is large enough, and any attempt to press them into service, for which they are unsuitable, will only be the cause of dissatisfaction and needless expense.

The Calculation of Constant-Voltage Transmission Lines

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THE REMARKABLE economies secured and the success [illegible] synchronous motors on a large scale for controlling the [illegible] transmission [illegible] constant-voltage system on a footing where it must be seriously considered, either for adoption or rejection, not only by the designers of new power projects, but also by those responsible for the management and operation of existing power systems of all sizes. In order to judge the new method fairly, it is necessary to make use of calculations specially adapted to constant-voltage transmission lines. In this article is given a collection of formulae which will be useful in the solution of most electrical problems connected with the design of such lines.

THE distinctive features of the constant-voltage system of operating transmission lines consist in the use of synchronous phase modifiers in large quantities at the receiving substations, and in their continual adjustment, either by hand control or by Tirrill regulators, so as to overcome voltage variation by changing the power-factor as required. This method is not to be confused with the common employment of synchronous motors with steam plants, where they are used to raise the power-factor as much as possible, but not to lower the power-factor at times nor to adjust it. The results obtained include that of controlling the voltage of lines at the receiving end, which is the rational place, instead of the distant supply end; of doubling the maximum power load of many existing lines, thus relieving overloaded lines and making extensions possible at small cost; of allowing lines to be built with heavier conductors, wider spacing, and higher reactance throughout than is the usual practice, and of increasing the economical distance of transmission.

The formulæ here presented are direct solutions, that is, the problems do not have to be solved by plotting curves or by a process of trial and error. The problems selected are those most likely to arise in practice. Graphical methods are not used except in one case, that of the circle diagram. In this article, the circle diagram has been made applicable to the solution of long constant-voltage lines according to the hyperbolic theory, and it is an extremely useful labor-saving device. With fine cross-section paper, very accurate results may be obtained. For greater accuracy, formulæ are given for calculating the results of the diagram. Tables of trigonometric functions of angles and tables of hyperbolic functions are not used, though the results of the hyperbolic theory are obtained with complete accuracy. It will be found convenient to make use of tables of transmission line constants.

The formulæ given apply not only to straight constant-voltage transmission lines, but also to constant-voltage networks. Each junction point of such a network has a definite voltage, and therefore, each line in the network can be calculated as a constant-voltage line, the variable item being the amount of real power transmitted over the line.

Circle Diagram. One of the first problems to be considered is, "What ratings in synchronous motors will be required for various loads?" The circle diagram, Fig. 1, provides a graphical solution, which, as it is short and comprehensive, is worth while drawing in all cases. This diagram, taking accurate account of all effects of line capacity and leakage, consists of parts of an exact circle and an ellipse. Let E_s be the constant line voltage at the supply end, and E the constant voltage at the receiving end. Let Y be the line admittance per conductor, and let $Z = R + jX$ be the impedance, where R is the resistance, and X the reactance, of one conductor. Let

$$E\left(1 + \frac{YZ}{2} + \frac{Y^2Z^2}{2\cdot3\cdot4} + \text{etc.}\right) = E' + jE''^{*}$$

and let

$$(R + jX)\left(1 + \frac{YZ}{2\cdot3} + \frac{Y^2Z^2}{2\cdot3\cdot4\cdot5} + \text{etc.}\right) = R' + jX'$$

Then, by the hyperbolic theory of transmission lines the supply voltage is

$$E_s = E' + jE'' + (P + jQ)(R' + jX')$$

where P is the in-phase component of current, in total amperes, at the receiver end, and Q the leading reactive component of current. Therefore

$$E_s^2 = (E' + PR' - QX')^2 + (E'' + PX' + QR')^2 \quad \text{.....(1)}$$

This reduces to the equation of a circle where Q is plotted for values of P.

Describe a circle whose center is (a, b) and whose radius is c, where

$$a = -\frac{E}{1000} \times \frac{E'R' + E''X'}{R'^2 + X'^2} \quad \text{........................(2)}$$

$$b = +\frac{E}{1000} \times \frac{E'X' - E''R'}{R'^2 + X'^2} \quad \text{........................(3)}$$

$$\text{and } c = +\frac{E}{1000} \times \frac{E_s}{\sqrt{R'^2 + X'^2}} \quad \text{........................(4)}$$

Now draw a straight line at an angle θ below the base line to represent the reactive k.v.a. of the load, cos θ being the power-factor, lagging, of the load. By adding its ordinates to those of the circle, in Fig. 1, by the use of a pair of dividers, plot the ellipse which gives the k.v.a. of synchronous motors required.

*For derivation of these equations and use of the convergent series, see "Transmission Line Formulas" by H. B. Dwight, p. 42, "Engineering Mathematics" by C. P. Steinmetz, p. 206, or other engineering text books.

For lines less than about 30 miles long, the effect of capacity is inappreciable, and the brackets containing the series in YZ may be omitted. Thus the short line formulæ will be the same as those given in this article, except that E' becomes E, E'' becomes zero, and R' and X' become R and X.

Theoretical Limit of Load—The calculated value in kilowatts of the theoretical limit to the load at the given voltages is

$$\mathrm{Kw} = c + a \quad \ldots\ldots (5)$$

that is, it is numerically less than c since a is negative. It may be read from the circle diagram as it is the farthest distance to the right reached by the circle or the ellipse.

Reactive K.v.a. in the Line at the Receiver End—For a more precise value than that obtained from the circle diagram, solve the following quadratic equation, which is obtained directly from (1):

$$a_1Q^2 - 2b_1Q + c_1 = 0$$

$$\text{where } a_1 = R'^2 + X'^2$$

$$b_1 = E'X' - E''R'$$

$$\text{and } c_1 = P^2(R'^2 + X'^2) + 2P(E'R' + E''X') + E'^2 + E''^2 - E_s^2$$

$$\text{Then } Q = \frac{b_1 - \sqrt{b_1^2 - a_1c_1}}{a_1} \quad \ldots\ldots (6)$$

Use only the negative value of the radical, as shown, since the smaller value of Q is the result required. Q is the reactive current, and $EQ \div 1\,000$, the reactive k.v.a. in the line at the receiver, for a given load in kilowatts, $EP \div 1\,000$. When Q, as found above, is positive, it represents leading reactive k.v.a. in the line at the receiver, and lagging when it is negative.

Line Power-Factor at the Receiver End—The power-factor at the receiver end, including the combined effect of the load and the phase modifiers, is

$$\frac{100\,P}{\sqrt{P^2 + Q^2}} \text{ percent} \quad \ldots\ldots (7)$$

where P is determined from the load in kilowatts, and Q is either read from the circle diagram or calculated by means of (6). The line power-factor is leading or lagging according as Q is positive or negative.

Reactive K.v.a. of Synchronous Motors—This may be read from the circle diagram, or it may be more accurately found by using the calculated value of Q in the expression

$$\frac{EQ + EmP}{1000} = \text{Reactive k.v.a.} \quad \ldots\ldots (8)$$

where m is a constant equal to $\sin\theta \div \cos\theta$, the power-factor of the load being $\cos\theta$. When the above expression is positive, the current in the line due to the synchronous motors is leading, and the motors have strong field current. When the expression is negative, the current is lagging.

Line Losses in Kilowatts—

$$\text{Let } A = E' + PR' - QX'$$

$$B = E'' + PX' + QR'$$

$$\text{and } C + jD = (P + jQ)\left(1 + \frac{YZ}{2} + \frac{Y^2Z^2}{2\cdot3\cdot4} + \text{etc.}\right)$$

$$+ EY\left(1 + \frac{YZ}{2\cdot3} + \frac{Y^2Z^2}{2\cdot3\cdot4\cdot5} + \text{etc.}\right)$$

where Q is found either from the circle diagram or from (6).

$$\text{Line Losses} = \frac{1}{1000}(AC + BD - EP) \text{ kilowatts.} \quad \ldots\ldots (9)$$

$$\textit{Kw at Generators} = \frac{1}{1000}(AC + BD) \quad \ldots\ldots (10)$$

$$\textit{K.v.a. at Generators} = \frac{1}{1000} E_s \sqrt{C^2 + D^2} \quad \ldots\ldots (11)$$

$$\textit{Power-Factor at Generators} = \frac{100(AC + BD)}{E_s\sqrt{C^2 + D^2}} \text{ percent.} \quad (12)$$

$$\textit{Reactive K.v.a. at Generators} = \frac{1}{1000}(AD - BC) \quad \ldots\ldots (13)$$

$$\textit{Percent Efficiency of the Transmission Line} = \frac{100\,EP}{AC + BD} \quad \ldots\ldots (14)$$

When this quantity is positive, the reactive k.v.a. and the power-factor at the generators are leading, and when it is negative they are lagging.

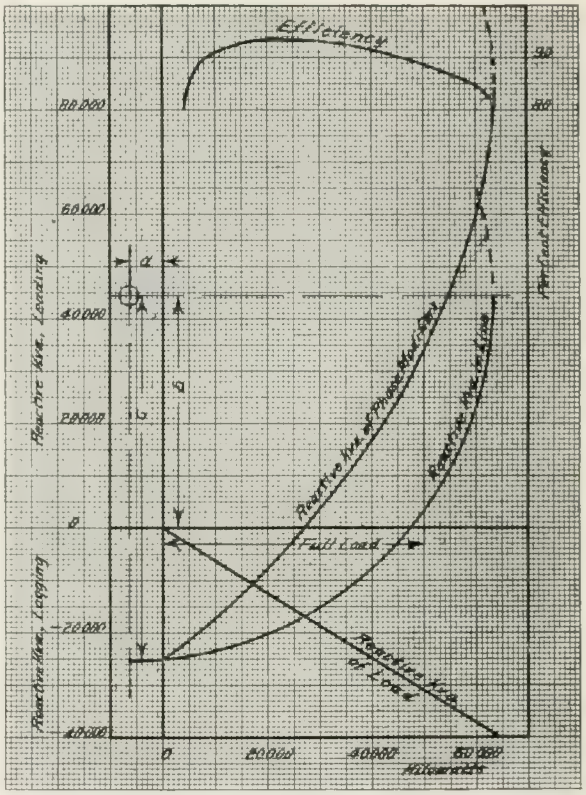


FIG. 1—CIRCLE DIAGRAM OF CONSTANT-VOLTAGE TRANSMISSION LINE

Single-Phase Lines—The above formulas are for three-phase and two-phase lines. For single-phase lines use $2\,R$ and $2\,X$ in place of R and X and use $0.5\,Y$ in place of Y.

Allowance for Extra Impedance—Only a very slight error is introduced, for power transmission lines, by adding the resistance and reactance of the transformers and protective reactance coils, referred to high tension, to the line resistance and reactance, when convergent series are used as in this article. The exact solution would involve treating the impedances at the ends as separate sections of the line, each section to be calculated by itself, but this method is long, and does not lend itself to the direct solution of the problems considered above.

EXAMPLE, 200-MILE CONSTANT-VOLTAGE LINE

Effect of capacity to be included in the calculations.
Conductor ....400 000 circ. mil. copper cable
Effective spacing.................................20 feet
Constant supply voltage..............Es = 150 000 volts
Constant receiver voltage..............E = 110 000 volts
Resistance per conductor, including transformers and protective coils...........R = 31.8 ohms
Reactance per conductor, including transformers and protective coils..........X = 244.4 ohms
Capacity susceptance per conductor..Y = + j0.001038 mhos
(Leakage is assumed to be zero.)
Full load delivered at receiver...............50 000 kilowatts
Power-factor of lcad, lagging...................85 percent
Frequency ....60 cycles

To Draw the Circle Diagram.—E′ + j E″ = 110 000 (0.875 + j 0.015) = 96 300 + j 1 700. R′ + j X′ = (31.8 + j 244.4) (0.958 + j0.0054) = 29.2 + j 234.4*

a = — 6 300 kw. (Equation 2).
b = + 44 400 k.v.a. (Equation 3).
c = + 69 900 k.v.a. (Equation 4).

The circle, straight line, and ellipse may now be drawn to make the complete diagram, which is drawn to scale for this problem, in Fig. 1. The theoretical maximum load for the voltages specified is:—

69 900 — 6 300 = 63 600 kw. (Equation 5)

The reactive k.v.a. in the line at the receiver end, when the delivered load is 50 000 kw, is EQ ÷ 1 000 where Q is found from the equation,—

$$5.58\, Q^2 + 2\, Q \times 2250 - 123\,200 = 0.\dagger$$

Then, $Q = \frac{-2250 + \sqrt{5\,070\,000 + 687\,000}}{5.58} = 28$ (Equation 6)

The reactive k.v.a. $= \frac{110\,000}{1\,000} \times 28 = 3100$ k.v.a. (leading).

The line power-factor at the receiver end is 99.8 percent, and is leading since Q, as found above, is positive. (Equation 7.)

The capacity of synchronous motors required to maintain constant voltage for a load of 50 000 kilowatts, that is, to correct the power-factor from 85 percent lagging to 99.8 percent leading, is,—

$$\frac{110\,000}{1000}\left(28 + \frac{0.527}{0.850} \times 454\right) = 34\,100 \text{ k.v.a.} \quad \text{(Equation 8).}$$

For other problems it is necessary to make use of the following quantities:—

$A + j\,B = 102\,900 + j\,109\,100$
$C + j\,D = 397 + j\,141$

The generator power-factor, for a load of 50 000 kilowatts delivered at the receiver end of the line, is,—

$$\frac{100\,(409 + 154)}{1.50 \times 421} = 89.1 \text{ percent.} \quad \text{(Equation 12).}$$

The generator reactive k.v.a. is,—

$$\frac{1}{1000}\,(102\,900 \times 141 - 109\,100 \times 397) = -28\,800 \text{ k.v.a.} \quad \text{(Equation 13).}$$

Since this quantity is negative, the power-factor at the generators is lagging, and the generators therefore require a strong field current.

The efficiency of the transmission line, for 50 000 kw load, is,—

$$\frac{100 \times 50\,000\,000}{102\,900 \times 397 + 109\,100 \times 141} = 88.8 \text{ percent.} \quad \text{(Equation 14).}$$

---

*Y = G + jB. When G = 0 as in this case, Y = jB. Substituting this value, and Z = R + jX into the equation defining E′ + jE″ we get

$$E' + jE'' = E\left[1 - \frac{BX}{2} + \frac{B^2(X^2 - R^2)}{24} \cdots + j\left(\frac{RB}{2} - \frac{RB^2X}{12} \cdots\right)\right]$$

into which the numerical values can be substituted directly. The other equations are solved similarly.

†For simplicity this equation has been divided by 10 000.

Shop Testing of Electrical Apparatus---XX

THREE-PHASE TRANSFORMERS

IN MOST RESPECTS the tests on three-phase transformers are similar to the corresponding tests on single-phase transformers, the difference, where there is any, being due to the added complication of windings and the greater number of possible connections. The logical order in which the individual tests are made is also the same for both single-phase and three-phase transformers; that is, in order to perform the individual tests in quick succession, each one being as little affected as possible by those just completed, the following is the advisable order:—

1—Ratio
2—Polarity
3—Parallel test
4—Resistance
5—Core loss and exciting current
6—Copper loss and impedance
7—Temperature run
8—Insulation test
 a—Insulation resistance
 b—Disruptive test
 c—Overpotential test
9—Regulation
10—Efficiency

The tests are governed to some extent by local conditions, and also by the method of cooling and the service for which the transformers are designed; that is, according to whether they are self-cooled, water-cooled or air-cooled and whether they are for use on transmission or distributing circuits.

RATIO

The most convenient method of making the ratio test of a three-phase transformer is to test each phase separately, as previously described for single-phase transformers. If the windings of the transformer cannot be disconnected readily, a three-phase voltage may be used and the three-phase ratio checked directly.

POLARITY

For this test the transformer should be connected as shown in Fig. 1. Lead C on the high-tension winding should be connected to lead D on the low-tension and the three-phase voltage applied on leads A, B, and C. Then measure the voltages A-B, A-C, B-C, D-E, E-F, D-F, A-E, A-F, B-E and B-F. The first three voltages will of course be equal, and the fourth, fifth and sixth will be equal, the ratio of the two different sets being the ratio of transformation. The seventh, eighth, ninth and tenth voltages—that

is, *A-E*, *A-F*, *B-E*, and *B-F*, are the voltages that determine the polarity, their relative values depending upon the connections.*

PARALLEL TEST

When it is possible to isolate the windings, or where it is desired to test the individual coils of one phase, the parallel test on a three-phase transformer is

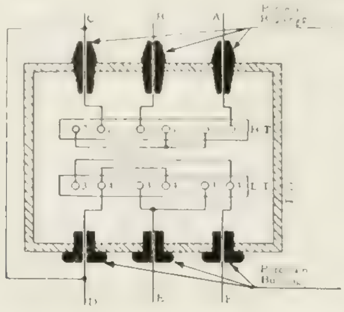


FIG. 1—DIAGRAM OF CONNECTIONS FOR POLARITY TEST

made in exactly the same manner as for a single-phase transformer, each leg of the three-phase transformer being tested separately.

RESISTANCE

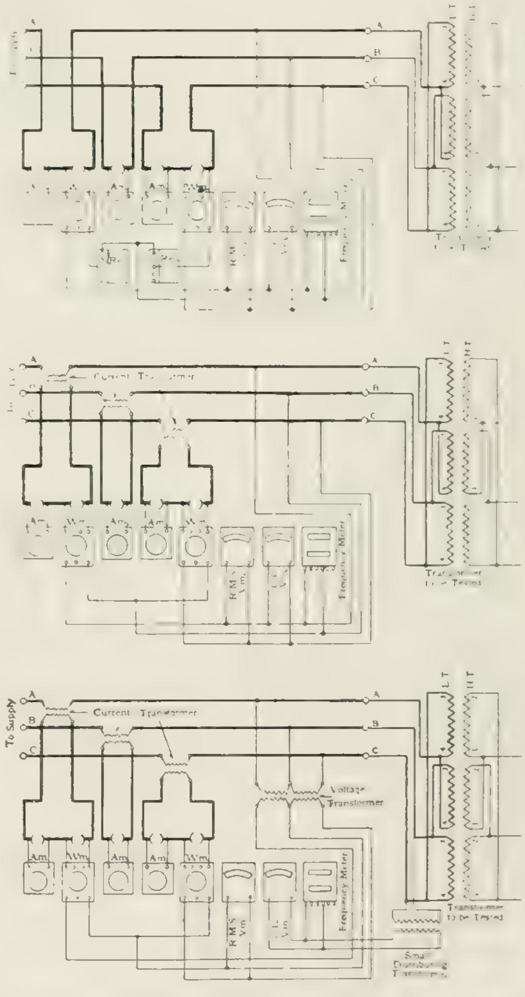
Since all leads from the winding of a three-phase transformer are customarily brought to the terminal board separately, it is usually most convenient to measure the resistance of three-phase transformers with all the high-tension windings in series, and all the low-tension windings in series. This method is especially convenient when measuring hot resistances on account of the fact that the temperature run on a three-phase transformer is usually made with the windings connected in delta. If either winding is connected permanently in star or delta, the resistance between each pair of terminals should be measured and recorded in such a way as to leave no doubt as the connections used in the test.

CORE LOSS

The core loss must be taken with all the phases excited to full voltage, with the voltages in the correct phase relations. The transformer is connected according to whichever of the diagrams, Figs. 2, 3, or 4, is suitable to the conditions of the test, the same precautions being observed in bringing the potential up to full rated value, as with single-phase transformers. The core loss will then equal the algebraic sum of the wattmeter readings when the core-loss voltmeter registers the rated voltage of the transformer. Correction should be made for the losses in the voltmeters, potential transformers and the potential coils of the wattmeter, which are included in the wattmeter readings. The volt-amperes core loss equals EI ÷ 1.73 where *E* is the reading of the core loss voltmeter and *I* is the sum of the currents in all the lines.

COPPER LOSS AND IMPEDANCE

All precautions as described for the measurement of the copper loss and impedance of single-phase transformers apply as well to three-phase transformers. The simplest method of making this test is to apply it to each phase separately as described for single-phase transformers. Where this it inconvenient or where the saving of time is an object the total losses in the transformer on a three-phase circuit may be obtained by the same connections as are used in the core-loss test, Figs. 2, 3, or 4, except that the measurements are customarily made on the high-tension rather than on the low-tension side, and the transformer secondary is short-circuited. If desired, the ammeters may be inserted in the short-circuited secondary leads, instead of on the primary side. As in the core-loss test, the connections may be made to whichever side of the transformer is more convenient for the instruments available and the testing circuit.



FIGS. 2, 3 AND 4—METHODS OF CONNECTING TRANSFORMER FOR CORE LOSS TEST

Fig. 2 for small current at a moderate voltage.
Fig. 3 for large current at a low voltage.
Fig. 4 for large current at a high voltage.

If the transformers are excited from a three-phase e.m.f., care must be exercised that the currents in all three phases are the same. The normal current in each line is calculated from the formula

$$I = \frac{1000 \times \text{K.v.a.}}{1.73 \times E}$$

in which *I* is the current in one line, *E* is the poten-

*For a discussion of these relations see article by Mr W. M. McConahey in the JOURNAL for July, 1912, p. 613.

tial between phases and *K.v.a.* is the normal rated value of the transformer. The voltages between lines when full-load current is flowing in the transformer are the impedance voltages. These voltages should be observed at the same time that the wattmeter readings of copper loss are observed.

In this test it is not at all necessary that the impressed e.m.f.'s shall be in the correct phase relation,

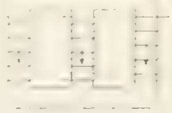


FIG. 5—DIAGRAM INDICATING DIRECTION OF FLUX IN A CORE-TYPE TRANSFORMER WITH SINGLE-PHASE CURRENT IN COILS WOUND IN THE SAME DIRECTION

and if desired all three phases may be simultaneously excited from a single-phase source. In a shell-type transformer this may be done by simply connecting both sides in delta, opening the delta on one side, and connecting the single-phase e.m.f. to the leads thus formed. In a core-type transformer it is necessary that the windings on one phase be reversed for this connection, as otherwise the fluxes in the three legs of the core will be all in the same direction, as shown in Fig. 5, and the impedance drop will be very large. The percent impedance drop of a delta-connected transformer tested in this way equals

$$\frac{100 \times \text{measured impedance voltage}}{3 \times \text{impressed voltage}}$$

The percent impedance drop of a star-connected transformer under these conditions equals

$$\frac{100 \times \text{measured impedance voltage}}{1.732 \times \text{impressed voltage}}$$

TEMPERATURE RUN

The temperature tests on three-phase transformers differ from those of the corresponding types of

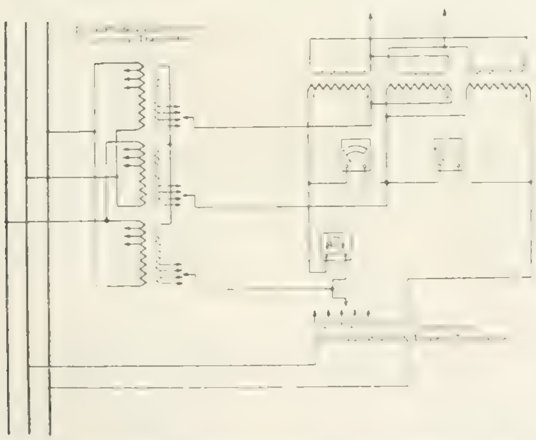


FIG. 6—CONNECTION DIAGRAM FOR A TEMPERATURE TEST

Loading single-phase and magnetizing three-phase, both on the same winding of the transformer

single-phase transformers in the methods of connection and the number and locations of the thermometers used to indicate the temperatures of the various parts. The transformer should be connected according to whichever of the schemes of connections shown in Figs. 6 and 7 is most suited to the conditions of the test. The connections shown in Fig. 6, may be applied to either the low-tension or high-tension windings; it is usually more convenient to test high potential transformers on the low-tension side and vice versa. With the scheme of connections shown in Fig. 7, both windings must be grounded as shown, in order to prevent excessive static strains between the windings and ground. If two exactly similar transformers are to be tested, the scheme of connections shown in Fig. 8 may be used. Before starting the run, the cold resistances of both windings should be measured with the respective windings connected in a delta, which is opened at one point.

One thermometer tube should be placed between the low-tension coils of each phase and, if the transformer is oil insulated, a thermometer for indicating the oil temperatures throughout the run should be hung with its bulb about two inches under the surface of the oil. A thermometer for indicating the temperature of the surrounding air should be hung in such a location as to indicate the average air temperature in the neighborhood of the transformer.

Having placed and read all thermometers and having the transformer correctly connected, the switch

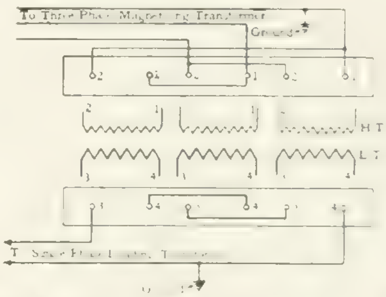


FIG. 7—TEMPERATURE TEST ON A THREE-PHASE TRANSFORMER

Loading single-phase on one winding and magnetizing three-phase on the other.

connecting the loading transformer to the power circuit should be closed, applying a low voltage to the transformer on test. The switch short-circuiting the ammeter should then be opened and the value of the current observed. By means of the variable-ratio loading transformer the current should be gradually increased to the normal value for the winding. The oil-switch connecting the magnetizing transformer to the power circuit should then be closed, and the voltage on the transformer raised to normal. The load current should be checked and, if necessary, readjusted to normal after the magnetizing voltage has been applied.

When the temperature of the transformer as indicated by the thermometer in the oil and coils has been constant for four consecutive half-hour readings, and the temperature of the surrounding air has not varied over 1.5 degrees during the four readings, the hot resistances of the respective windings should be measured. All preparations possible should be made before disconnecting the transformer on test

from the source of power. Unless otherwise desired for some special reason, the open delta resistances are taken, and the low-tension side is measured first. Any overload runs should be made in the same manner as the full-load run.

The above procedure applies to any self-cooled three-phase transformer and is similar to that for

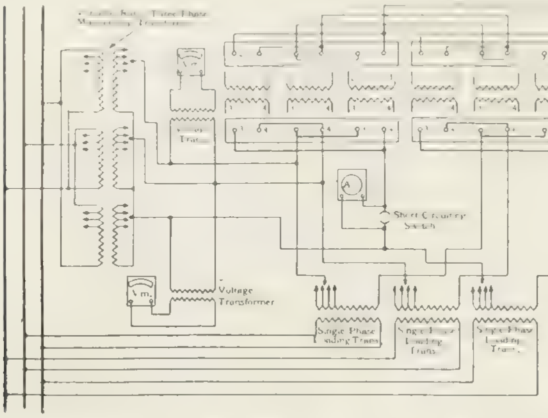
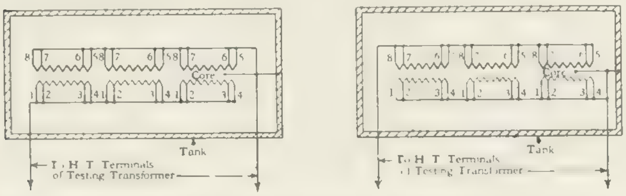


FIG. 8 DIAGRAM OF CONNECTIONS FOR LOADING TWO THREE-PHASE TRANSFORMERS IN OPPOSITION
Magnetizing and loading on the same windings.

any other method of cooling except that additional thermometers are located as follows:—

On water-cooled oil-filled transformers one thermometer should be placed with its bulb just under the surface of the oil, three in tubes for coil temperatures, that is one on each phase, one in the ingoing cooling water, one with its bulb protected by a felt pad on each cooling coil pipe at the discharge end and an inch or so from the tank, one in the common discharge of the cooling coils, and one for indicating the air temperature. The rate of flow of water through the cooling coils should be carefully regulated and adjusted.

On air blast transformers, one thermometer should be placed at some point near the intake of the blower supplying air; one in the air chamber near the base of the transformer; one on the core at each air outlet; from four to six on the coils of each phase of the transformer; one in the outgoing air from the core at each outlet. Otherwise the location of ther-



FIGS. 9 AND 10—DISRUPTIVE TESTS ON THREE-PHASE SHELL-TYPE TRANSFORMERS
Fig. 9—High-tension to low-tension and core.
Fig. 10—Low-tension to core.

mometers is as described above for all three-phase transformers.

During the run on an air-blast transformer the method of regulating and adjusting the air is exactly as described for single-phase transformers. When shutting down, the air blast, load current and magnetizing voltage should be stopped simultaneously, as nearly as possible. A series of readings should then be taken, indicating the maximum temperature by thermometer, as already described for single-phase transformers.

INSULATION TESTS

In general, the same insulation tests are made on three-phase transformers as are made on single-phase transformers, the only difference occurring when it becomes necessary to make the overpotential test on a three-phase core-type transformer with single-phase current.

Disruptive Tests.—When the overpotential test is to be made with three-phase current or if a shell-type transformer is to be tested with single-phase current, it should be connected as shown in Fig. 9, for the disruptive test from the high-tension windings to the low-tension windings and core, and Fig. 10 for disruptive test from the low-tension winding to the core. If a core-type transformer is to be tested with single-phase current, the disruptive test should be made on each phase separately. As shown in Fig. 11, when testing from one high-tension winding to the low-tension and the core, all windings of the other phases as well as the low-tension winding of the

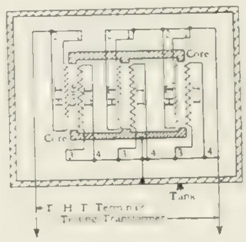


FIG. 11—DISRUPTIVE TEST ON A CORE-TYPE TRANSFORMER, HIGH-TENSION TO LOW-TENSION AND CORE, WITH SINGLE-PHASE VOLTAGE

phase being tested should be connected to the core in order that the insulation between the high tension windings of the different phases may be tested.

Overpotential Tests.—Whenever possible, overpotential tests on three-phase transformers should be made with three-phase current. In this case the transformer should be connected as for normal operation, and the same precautions and directions observed as for testing single-phase transformers. If it becomes necessary to make this test with single-phase current, each phase should be tested separately, as described for single-phase transformers.

REGULATION AND EFFICIENCY

The method of calculating the regulation and efficiency of three-phase transformers from the test data is exactly the same as for single-phase transformer. Ordinarily, in calculating regulation, the resistance and reactance drop of all three coils in series is determined and the result divided by three, the procedure then being as already described for single-phase transformers, giving the average or over-all regulation of the three-phase transformer.

In the same way the procedure for efficiency, as determined from the output or input and the losses, is identical, regardless of the number of phases.

Speed Characteristics of Direct-Current Motors

K. L. HANSEN AND C. G. LEWIS

BY CHANGING THE METHOD of exciting the fields of direct-current motors the needs of any installation can be met. In the following article the methods of taking care of the requirements of special applications by the use of different classes of motors are explained.

A GREAT variety of requirements must be met in the application of motors in ordinary industrial service. For instance, there are applications requiring very high starting torques, such as hoist and crane installations, where a motor must be able to exert the required torque without too heavy a current demand on the line; there are applications which make it necessary that the driving motor shall drop off in speed, and exert an increased torque when the load is suddenly applied. Examples of this are large shears and punches which, since they generally have a flywheel, demand that the motor speed shall drop off as the load comes on so that the flywheel may help the motor during the peak loads. There are also cases which require a constant speed over the whole range of load such as fan and blower installations.

The special feature of the performance of direct-current motors, which distinguishes between series, shunt and compound motors is the speed characteristic, or the change in speed with a change in load. At constant applied voltage this change is dependent upon the change in the resultant flux per pole as the load changes, and on the internal resistance drop in voltage. Assuming constant field excitation, the resultant magneto-motive force at any load depends on several different conditions. It is affected by the armature magnetomotive force, more or less according to the brush position. If the brushes are not set on the neutral position, some of the armature ampere-turns are either directly opposed or added to the field ampere-turns according to whether the brushes are given a forward or backward lead. In commutating-pole motors the resultant magnetomotive-force is affected by the degree of compensation. If the motor is over-compensated, the armature coils which are undergoing commutation have a current flowing in them in such a direction that the resulting magnetomotive-force has a demagnetizing effect on the field. If the motor is under-compensated the coils being commutated have an opposite effect.

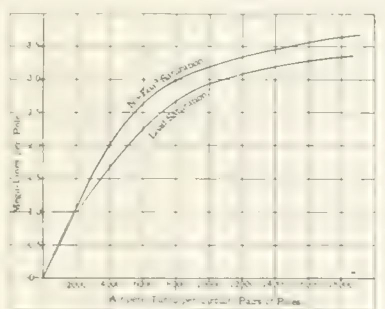


FIG. 1—SATURATION CURVES OF A 37.5 HORSE-POWER, 4 POLE, 230 VOLT, 540 R.P.M. SERIES-WOUND DIRECT-CURRENT MOTOR

Since these conditions determine the resultant magnetomotive-force, they determine the flux more or less according to the saturation of the pole tips and lengths of air-gaps, and hence, assuming constant field excitation, they determine the speed characteristic. This is shown by the voltage formula for direct-current motors:—

$$R_s = \frac{E}{2N} \times \frac{1}{P\phi} \text{ for a two-circuit armature;}$$

$$\text{or } R_s = \frac{E}{2N} \times \frac{10}{\phi} \text{ for a multiple wound armature.}$$

Where,

E = induced e.m.f

N = number of armature turns.

P = number of pairs of poles.

Φ = flux in c. g. s. lines per pole.

R_s = revolutions per second.

THE SERIES MOTOR.

As an illustration of a series motor consider a 37.5 horse-power, four-pole, 230 volt, 540 r.p.m., mill motor with a two-circuit winding, having a total of 210 turns on the armature and 32 turns per series coil. The motor is supplied with commutating poles and operates with the brushes on the no-load neutral, so there is no demagnetizing effect due to the armature current when the motor is loaded. There is, however, a distortion of the main field under load due to cross magnetization, and the total flux per pole will be lessened on account of the unequal saturation of the two sides of the poles. The m.m.f. of the field varies directly with the current and a curve may be plotted showing the net flux per pole at any load, as shown in Fig. 1. The total resistance of armature, series and commutating field coils is 0.13 ohms. The current at full load is 140 amperes, hence the total IR drop of the windings is 18 volts, and the induced volts, 212. The series ampere-turns per circuit at full load = 8960 and the total flux per pole = 2.8

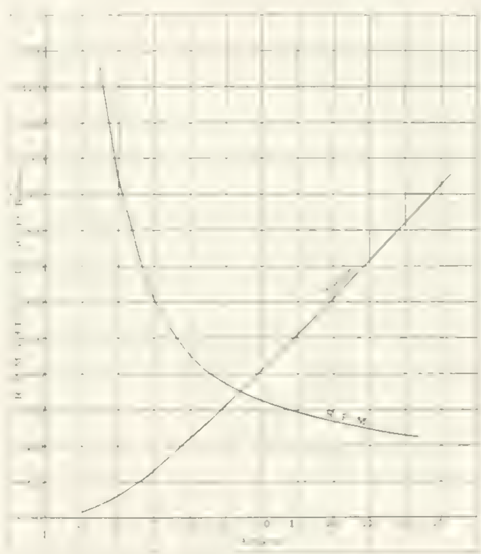


FIG. 2—CURVES SHOWING THE [illegible] RELATION BETWEEN TORQUE AND SPEED FOR THE MOTOR SHOWN IN FIG. 1

megalines. Substituting in the formula for speed,

$$\text{R.p.m.} = \frac{212 \times 10^8 \times 60}{2 \times 420 \times 2\,800\,000} = 540$$

In the same way the speed may be calculated at any load and a curve plotted with amperes load as abscissae and r.p.m. as ordinates, as shown in Fig. 2.

Before saturation is reached the flux increases almost in direct proportion to the current, and the torque varies about as the square of the current. At heavy loads, when the magnetic circuit becomes saturated, the flux becomes almost constant, and the torque then increases in direct proportion to the current. Over the entire operating range, however, there is some increase in flux with an increase in current and consequently the series motor on overload develops a greater torque at a lower speed and with less current consumption than a motor with constant field excitation. It also develops a greater starting torque and accelerates more rapidly to its normal speed than a shunt motor.

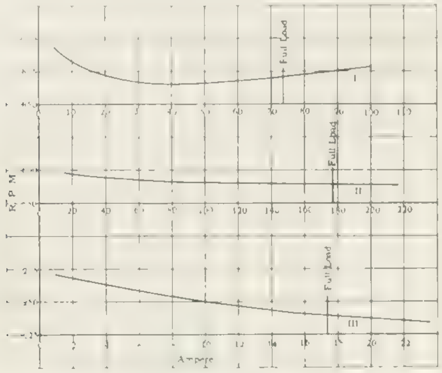


FIG. 3—CURVES SHOWING VARIOUS TYPES OF SPEED CHARACTERISTICS FOR SHUNT MOTORS

Curve I from a 20 hp, 4 pole, 230 volt, 900 r.p.m. motor.
Curve II from a 50 hp, 4 pole, 230 volt, 575 r.p.m. motor.
Curve III from a 4 hp, 4 pole, 230 volt, 235 r.p.m. motor.

These inherent characteristics of the series motor—high starting torque and variation of speed with the load—make it suitable for many applications, such as hoists, cranes, railways, etc. In the case of railways, heavy starting torques are required to overcome the inertia of trains or cars. In the case of hoists, small weights are lifted more quickly than heavier ones and varying speed motors are desirable. If the load be removed from a series motor its excitation becomes very small and the motor may attain excessive speed. It should, therefore, never be applied where there is any possibility that its load will be entirely removed, as for instance in the case of belt drives.

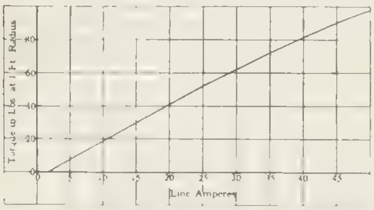


FIG. 4—TORQUE CURVE OF A 20 HORSE-POWER, 550 VOLT, 1 700 R.P.M SHUNT MOTOR

THE SHUNT MOTOR

A shunt motor maintains in general a constant speed with a change in load. Since in the shunt wound motor the exciting winding is connected directly across the line at all times, the excitation is constant at all loads, and therefore the speed characteristic of shunt motors depends entirely on the internal voltage drop of the motor, the armature reaction and the position of the brushes. Since, as is generally the case with the commutating-pole motors now in use, the brushes are in the neutral position, it will be assumed that they are so placed. Then the speed characteristic of a shunt motor depends on whether the IR drop or the armature reaction has the predominating effect. If the former is the stronger, the speed curve of the motor will droop with increasing load; if the latter predominates the speed will rise with the load. Usually, however, the IR drop effect is stronger on one part of the curve, generally at light loads, and at the heavier loads the distortion and consequent field weakening is the stronger effect.

Several speed characteristics of shunt motors taken from tests are shown in Fig. 3. In curve *I*, up to approximately one-half full load, the speed drops off, since over this range the internal IR drop of the motor has a stronger effect than field weakening due to distortion, while at heavier loads the speed tends to increase. A motor with a speed characteristic like this is very liable to be unstable over the range where the curve is rising, for the greater the load the higher will be the speed unless some other effects come in. Motors having this type of speed curve should be avoided. Curve *II* is the ideal curve for a shunt motor. In this case the IR drop nearly counteracts the rise in speed which would obtain if only the action of the field weakening due to distortion were present. Curve *III* shows a distinctly drooping speed characteristic. There is a comparatively large internal drop in this motor. Slow-speed motors such as this one have a larger IR drop than higher speed motors and, therefore, their speed curve droops more.

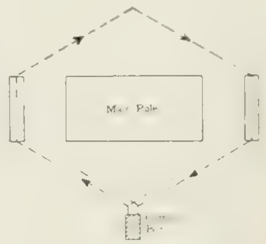


FIG. 5—WITH THE COIL IN THE POSITION SHOWN THE FLUX DUE TO THE CURRENT FLOWING IN IT MUST EITHER ASSIST OR OPPOSE THE MAIN POLE FLUX

The torque in shunt-wound motors is proportional to the current until the field weakening due to distortion begins to have an effect, when the torque becomes less than proportional to the current. This is shown from the equation for torque in direct-current motors:

$$T = \frac{2n \; I \; \Phi}{8.52 \; (10)^8}$$

Where,

T = internal torque of motor
n = total number of conductors
I = armature current per conductor
Φ = net flux in c. g. s. lines.

The value of Φ decreases with the load very slightly until fairly heavy loads are reached. A typical torque curve of a shunt motor is shown in Fig. 4.

Shunt motors are most useful where a constant torque is required at a constant speed. Motors which are to be used for fans and blowers of various kinds where a high starting torque is not necessary and where a constant torque only need be exerted when the motor is up to speed, should be shunt wound. Mo-

tors for driving line shafting, motors for running grinding and buffing machines, for centrifugal pumps and innumerable other similar applications require the characteristics of the shunt-wound machine.

That the degree with which the commutating pole compensates for the reactance voltage induced in the coils undergoing commutation has an effect on the speed characteristic, notably on that of the shunt motor, may be seen from Fig. 5. The armature coil is shown in the position of short-circuit, and in this position makes a complete turn around the main pole. Therefore, if there happens to be any current flowing in this coil a flux will be produced which either adds to or subtracts from the main field flux. When the commutating-pole exactly compensates for the reactance voltage there is no current flowing in the armature coil short-circuited by the brushes. However, when the motor is over-compensated, that is when the commutating-pole more than compensates for the short-circuit voltage of the armature coils, a current flows in such a direction as to demagnetize the main field, and vice versa.

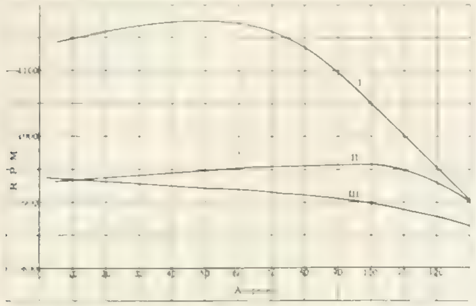


FIG. 6—SPEED CURVES ON A 30 HORSE-POWER, 230 VOLT, 450-600 R.P.M. ELEVATOR MOTOR
Showing various commutating pole effects.

Curve *I* of Fig. 6 which shows the original speed characteristic of this motor, brings out this point. The speed rises, up to a little less than one-half full load, and then drops off rapidly as the load is increased. Up to one-half full load the brush potential curves of the motor showed it to be slightly over-compensated. When the load is further increased the brush potential curves show strong under-compensation, and on account of this the speed drops off very quickly, as the curve shows. This sudden under-compensation is due to saturation in the commutating-pole circuit, and in order to cure this, commutating poles of larger cross-section were installed in the motor. After this change the curve shown in Curve *II*, Fig. 6, was obtained. As may be seen from this curve the commutating-pole circuit does not start to saturate until the current reaches about 110 amperes, where before saturation commenced at about 50 amperes. The speed curve still had the rising characteristic since the motor was over-compensated, so in order to give the machine a drooping characteristic the commutating pole air-gap was increased. The final curve, shown in Curve *III*, Fig. 6, shows a distinct drooping characteristic.

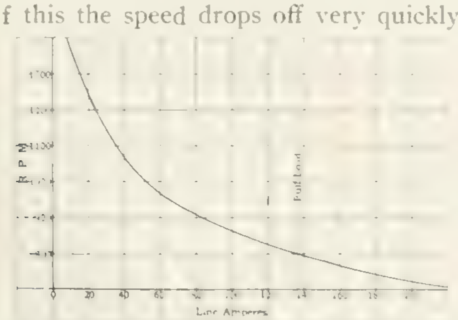


FIG. 7—SPEED CHARACTERISTIC OF A 37.5 HORSE-POWER, 4 POLE 230 VOLT 540 R.P.M. COMPOUND WOUND MILL MOTOR
Showing the effect of heavy compounding.

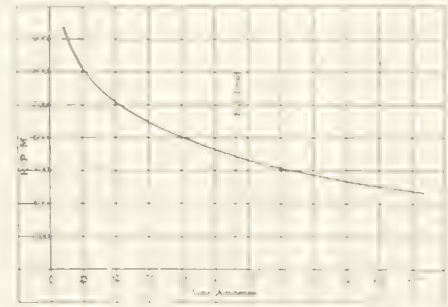


FIG. 8—SPEED CURVE OF A 40 H[illegible] 800-1400 R.P.M. BENDING-ROLL MOTOR
This type of motor is especially heavily compounded, giving it almost the speed characteristic of the series motor.

COMPOUND MOTOR

In practice many applications are encountered for which a series motor would be suitable except for the fact that it tends to race at no load. It also frequently happens that motors with speed characteristics of the shunt motor and the starting characteristics of the series motor are wanted. In such cases compound-wound motors should be used. The compounding may vary all the way from series motors with just sufficient shunt ampere-turns to keep them from running away at no load to motors with almost constant speed characteristics, as shown in Figs. 7, 8 and 9. In the majority of cases, the shunt and series ampere-turns are proportioned to give approximately 20 percent speed variation from no load to full load. The compound motor covers a wide field of application, overlapping somewhat those of the series and shunt motors.

SPEED CONTROL

The speed of direct-current motors may be adjusted by controlling the field. This characteristic is very useful in industrial applications. The speed characteristic varies considerably at the different field strengths due the changes in saturation. In general, the speed regulation is larger at weak field strength, since the change in flux from no load to full load is a larger percentage of the net flux than with a strong field. The speed regulation of a motor is its most important characteristic from the standpoint of application and, therefore, the application should be studied carefully in this respect and a motor selected to suit.

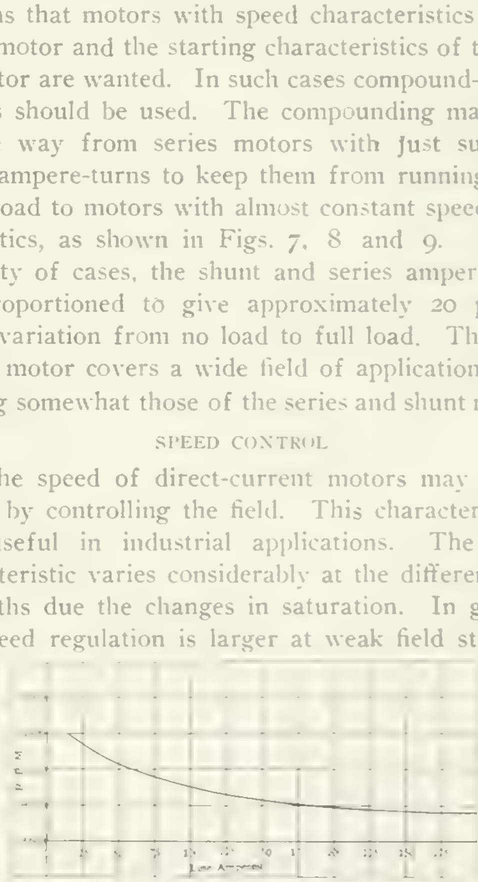


FIG. 9—SPEED CHARACTERISTIC OF A 50 HORSE-POWER 4 POLE 230 VOLT, 1700 R.P.M. MOTOR, COMPOUNDED TO DRIVE A CENTRIFUGAL PUMP

The Journal Question Box

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1111—**Commutating Pole Motor**—We have a bi pole motor with two commutating poles (the usual commercial type of motor) and we wish to change this motor to the one commutating pole type. What change must we make in the motor and what must be the polarity of this one commutating pole. S. S. C. (N. Y.)

When one commutating pole with its coil is removed the polarity of the remaining pole has to be the same as it was before the other pole was removed. The number of turns on the remaining pole, however, should be increased, which increase can be calculated approximately as follows:—No. of turns to be added to remaining coil = Present number of turns per commutating pole coil minus (number of commutator bars × turns per armature coil ÷ 4). The removal of one commutating pole is undesirable as on account of the increase in the flux of the remaining pole, this pole will become more saturated, which will decrease the overload capacity of the machine. Aside from this the removal of one pole will cause an unbalanced magnetic pull on the armature. A. B.

1112—**Transformer Connections**—For driving an air compressor on construction work I have been sent two 220 volt, two-phase induction motors and two single-phase transformers 2 200 to 220/110 volts and three wire switches. The only available current is 2 200 volt, three-phase, three-wire, with grounded

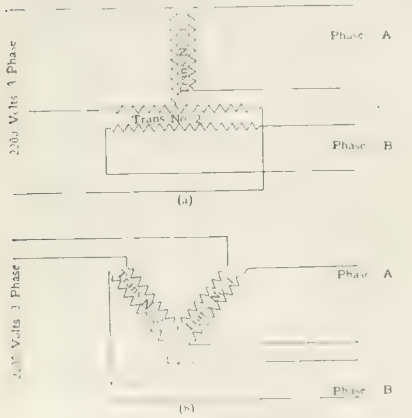


FIG. 1112 (a) AND (b)

neutral. How must I connect up the transformers to obtain two-phase, three-wire, 220 volt current or something that will approximate it closely enough to operate a motor satisfactorily for a temporary installation? E. C. M. (CALIF.)

If the middle point of the 2 200 volt transformer winding is accessible, the transformers can be connected up according to Fig. 1112 (a). With the transformers connected for 2 200 to 220 volts, phase *A* will be operating at 190 volts and phase *B* at 220 volts. If the middle point of the 2 200 volt winding is not accessible, the transformers can be connected in open-V as shown by Fig. 1112 (b). This will give 220 volts on both phases *A* and *B* but they will be 60 electrical degrees apart instead of 90. This will somewhat reduce the starting torque as well as the pull-out torque over that of normal operation. Both of the above arrangements will greatly unbalance the motor currents, so that the motor capacity may be greatly reduced,—possibly so much that the operation will be unsatisfactory. J. F. P.

1113—**Stresses Between Conductors**—Is there any published data giving mechanical stresses due to short circuits on the busses and switching connections of hydro-electric generating stations? J. R. V. W. (NEW YORK)

We know of no data published on this subject as the result of actual tests. An idea of the stresses involved may be obtained from the following formulae for the mutual attraction or repulsion between two straight parallel conductors carrying current:—$F = 2.04 i_1 i_2 (l/b) 10^{-8}$ where F = kilograms; i_1 and i_2 = the currents in the wires expressed in amperes; l = the length of conductor and b = the separation between the wires, expressed in the same units. The force will be an attraction if the currents are flowing in the same direction, and vice versa. For a further explanation of this formula see Karapetoff's "Magnetic Circuits," p. 257. C. R. R.

1114—**Transformation from Two-Phase to Four-Wire, Three-Phase**—The answer to question 922 shows the use of three transformers. Can this transformation to four-wire, three-phase be made with two transformers and if so, what are the taps? S. C. W. (MO.)

Transformation from two-phase to four-wire three-phase can be made by

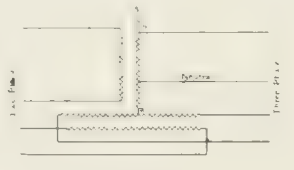


FIG. 1114 (a)

means of two transformers as shown by Fig. 1114 (a). This is the two phase-three phase "Scott" connection with an extra lead brought out from the neutral point at *O*. The distance *a* to *O* should be 28.9 percent and *a* to *b* 86.6 percent of the winding. J. F. P.

1115—**Grounding Transmission Line**—(a) What would be the objections to grounding the top wire of a delta connected transmission line and using it both as conductor and ground wire? (b)—We have an 85 000 volt, star connected and grounded transmission system and are contemplating using for small extensions, a single-phase feeder with one wire grounded as shown in Fig. 1115 (a). Are there any practical objections to this? What abnormal conditions, if any, would take place on the main transmission line or feeder due to this installation? The unbalancing would be about two percent. H. G. H. (MEXICO)

An objection to (a) is that the potential to ground of the two lines that are not grounded will be increased 73 percent over what it would be with all three lines isolated. Unless the line is liberally

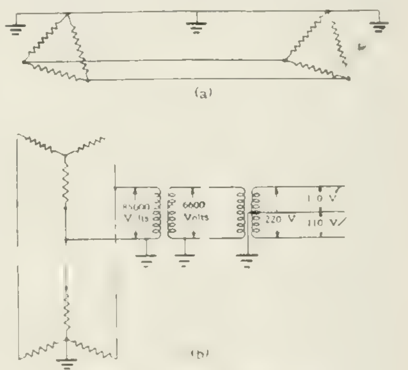


FIG. 1115 (a) AND (b)

insulated this may cause trouble. The system connected up according to (b) would have one phase of the three-phase system short-circuited. The ground on the single-phase line is equivalent to grounding one line of the three-phase system. This in connection with the grounded neutral forms a short-circuit for one phase. By omitting the ground on the 85 000 volt side of the single-phase line the system should operate satisfactorily. J. F. P.

1116—**Exciting Current of Transformers**—What percent of full-load current is the open circuit current of small distributing transformers, (about 50 kilowatt capacity) and large power transformers (about 5 000 kilowatt capacity)—(1) With cores of the old steel; (2) With cores of the new silicon steel. Is there not quite a large capacity current in large high voltage (85 000 volts or more) transformers? What is the value in percent of full-load current of this component, and is it not in opposition (180 degrees) to the magnetizing current. H. G. H. (MEXICO)

The open circuit current of a transformer is the vector sum of the exciting current and the dielectric charging current (capacity current). Both of these components are so variable for different types and makes of transformers that it is difficult to give accurate figures of their values. The results of a number

of tests made for determining these values is given in a paper by Mr. W. W. Lewis in the Proceedings of the American Institute of Electrical Engineers, for February, 1913, p. 490. Transformers built of the old steel will generally be found to take a smaller exciting current than transformers with silicon steel. The capacity current is approximately 180 degrees out of phase with the exciting current. J. F. P.

1117—**Drying Cable**—What is the best way to dry out a nine conductor paper insulated lead covered cable. The conductors are 2/0; the cable is 400 feet long laid in six inch cast iron conduit under a canal. J. G. K. (ONTARIO)

If this conductor is wet throughout it cannot be successfully dried except by stripping the lead off, drying it in heated vacuum impregnating tanks, and replacing the lead sheath. This of course can be accomplished only in the factory. If it is wet at one end only the moisture probably has not penetrated very far, as most cables are impregnated with moisture proof compounds. In such a case it may be possible to cut off the wet end. If the cable is not sufficiently long to allow cutting any off, and the moisture has not penetrated very far, it may be driven off by passing current through the conductors sufficient to heat the cable without injuring the insulation. This same statement applies to a hole in the middle of the cable. If the moisture has not penetrated very far on each side of the hole it may be driven out by passing current through the conductor and the hole then patched. Short lengths of cable have been dried out by pouring melted impregnating compound over the entire cable until the compound inside the cable becomes plastic or fluid. One end of the cable is then elevated and moulten compound poured in until it runs out at the other end. By continuing the flow of compound until that in the cable is entirely replaced, practically all the moisture will be removed. In this case care must be exercised that air bubbles are not included in the molten compound and the lower end of the cable must be stopped up before the pouring is stopped at the upper end so that when the cable cools it will be entirely filled with compound. The cable should be carefully tested for insulation resistance before being again placed in service. Unimpregnated cables, such as are used for signal and telephone work, are frequently dried out by forcing compressed air (which has been dried by passing through calcium chloride) through the cable. This method is of course impossible with a power cable which has been impregnated with a solid compound. R. E. P.

1118—**Lightning Protection of Direct-Current Circuits**—How should a direct-current 500-250 volt, three-wire circuit with the neutral grounded be protected from lightning or surges? In case of a surge what kind of potential, plus or minus, piles up at the negative terminal of a machine; at the positive terminal? How is it taken care of? C. F. P. (ONTARIO)

Lightning protection is not usually provided for 500-250 volt three-wire circuits with the neutral grounded. Usually these circuits are short and located in the thickly settled parts of cities where the many other overhead wires and the steel frame buildings afford considerable protection from lightning disturbances. If, however, protection is required the power house would be best protected by single cell electrolytic arresters connected to ground from each of the outer line wires. For line protection or cheaper station protection the well-known "Multipath" type of arrester so long used on 500 volt direct-current trolley circuits would be best suited. If used in the station two or more "Multipath" arresters should be used in parallel. In the case of a surge potential piles up at the terminals of the same polarity as the terminals themselves. On the recoil the potential falls and if the surge is very severe may reverse in polarity, but the potential is always higher when the polarity is the same as that of the terminal in question. Lightning arresters and choke coils afford protection against surges in the same way as against external lightning, but recurrent surges due to arcing grounds, etc., will overheat and burn up the arresters if allowed to continue. Q. A. B.

1119—**Iron Wire for Transmission**—We have a 6 600 volt, three-phase, 60 cycle transmission line, which we are about to extend for a distance of 4 000 feet, to take on a mixed lighting and induction motor load of about 20 kilowatts. We would like to use the ordinary telephone wire for this extension, as apparently the losses from ohmic resistance would be small when using No. 8 soft iron wire, but we have never had any experience with the use of iron wire for such purposes, and would like to know whether we are likely to encounter any serious trouble on account of reactance or other causes in making this use of iron wire. Our preference for iron wire rather than copper is the fact of its being mechanically so much better able to stand up under severe winter and sleet conditions. O. W. M. (WIS.)

If the ohmic loss is within reason when using No. 8 iron wire the slightly higher reactance due to using magnetic material will not be sufficient to prevent its use. P. M. [illegible]

1120—**Motors in Parallel**—We have two 40 horse-power direct-current series crane motors connected through drum controllers to run in series and parallel, both being connected mechanically to the same shaft. What is the best way to determine whether the field windings are properly connected and whether each motor takes its proper share of the load? J. G. K. (ONTARIO)

In order to determine whether the load is divided equally between the two motors, an ammeter should be connected in each of the two armature circuits, while the two motors are connected in parallel, and readings should be taken at different loads. If this shows that one motor is consuming considerably more than one-half of the total current, the fields of the two motors should be connected crosswise i.e. the field of the one motor should be in series with the armature of the other motor. If the motors should be connected this way already then they should be changed back to each armature being in series with its own field in case the armature shows an unequal load distribution. A. B.

1121—**Operation of Synchronous Motor**—(a) With a motor generator set consisting of a self-starting synchronous motor, provided with a short-circuited winding in the rotor and started by means of a two-point starting compensator, the motor being direct connected to a direct-cur- [illegible] standard practice in reference to arrangement of the synchronous motor field during the starting and running positions of the starting compensator? (b) What objection would there be to permanently connecting the field of the synchronous motor to the main leads of the direct-current generator, the synchronous motor field rheostat, of course, to be in series with the field of motor? (c) I believe it would be possible with this connection, by cutting all the resistance into the synchronous motor field circuit and also into the field circuit of the direct-current generator to start the synchronous motor as an induction motor and after it has fallen in synchronism to properly adjust its field by means of the two field rheostats and then throw the starting compensator to the running position. (d) To what extent does this method induce a high voltage in the motor field circuit, which would be transmitted to the armature of the direct-current generator? (e) I believe one standard method of arrangement is to provide a double-throw, double-pole switch for the synchronous motor field circuit, this switch being equipped with discharge resistance clip and discharge resistance and so wired that during the period of the starting of the synchronous motor it is thrown in one position, short-circuiting the field of the synchronous motor through the field rheostat and after the motor has reached synchronous speed and fallen into step, the double-throw field switch is thrown to the other position connecting the field of the synchroonus motor to the source of excitation, the synchronous motor field rheostat being still in series with it. I believe also that in some cases this double-throw switch, instead of being wired so that in one position it short-circuits the field of the synchronous motor through the field rheostat, is arranged so that in this position the field of the synchronous motor receives its excitation from a separate source and one independent of that from which the excitation is received when the switch is in the other position. With this arrangement, I assume that the field circuit of the synchronous motor is opened during the period of starting. In view of the fact that this arrangement would induce a high voltage in the field winding, would not this method be somewhat objectionable and make it necessary to provide a high insulation on the field winding of the synchronous motor? R. P. H. (W. VA.)

(a)—The standard practice of the Westinghouse Company is to start synchronous motors with the fields short circuited, although in some special cases the field circuit may be open. It is the standard practice of some other manufacturers to use open fields when starting. The field should be excited before throwing to the running tap. (b and c)—There is no objection to connecting the motor field to the generator terminals. With this connection the starting operation will be as stated. (d)—A high voltage is induced only when the field circuit is open. With the field connected across the generator armature, a small alternating current will circulate during starting, but the voltage will all be absorbed. (e)—The state-

ment regarding one standard method of field connection with double-throw switch is correct. We are not aware of any installation where a double-throw switch is used to provide two separate sources of excitation, but this is entirely feasible. In using this scheme and also the short-circuited field when starting, the discharge resistance should be made suitable for the short-circuit position. In case the field is not short circuited during starting, suitable insulation should be provided on the coils to take care of the voltage induced. R. A. M.

1122—Operation of Gasoline Electric Car—Can you give any information as to the operating cost per mile of a gasoline-electric railway car? W. E. E. (PENNA.)

Operating costs of gasoline-electric cars vary from 11 to 35 cents per car-mile. Local conditions, length of run, weight of car, type of equipment, cost of raw materials, all enter into total costs. Therefore, a comparison should take into account all of these conditions. We suggest that the best gauge for estimating the efficiency of the motor is, the average speed per hour, weight of car, average miles per hour for schedule, average grades on the line in question and the resultant miles per gallon of gasoline or combustible. F. E. D.

1123—Effective Resistance as Skin Effect—The skin effect factor is usually defined as that number by which the resistance of a circuit to a continuous current must be multiplied to give the actual resistance to an alternating current. If this gives the actual resistance to the alternating current, then why is this actual resistance not used in computing the I^2R losses on an alternating-current system? Also in this connection, assuming perfect insulation, are there any other than the I^2R losses to be considered in computing the loss in a lead covered cable or high tension transmission. W. G. S. (TEXAS)

At commercial frequencies the skin effect in conductors is not of commercial importance. However, the actual resistance to alternating current should be used to calculate the I^2R losses. For a given total current a uniform distribution gives the lowest copper loss in a conductor because loss in any elementary path varies with the square of the current in that element. When conductors are large enough to have appreciable skin effect, the increased current density near the outside of the conductor and the decreased current density at the center cause an increase in the equivalent resistance and copper loss. The losses in a lead covered cable are the I^2R losses due to current in the conductors, the eddy currents in the sheath, I^2R losses due to leakage of current through the insulation, which losses are independent of frequency, I^2R losses in the insulation due to the insulation absorption currents, which losses vary with some power of the frequency, and losses due to dielectric hysteresis or friction losses in the insulation because it is not perfectly elastic. Dielectric hysteresis varies directly with the frequency. L. W. C.

1124—Capacity of Condenser—Kindly furnish a formula for determining the capacity of a condenser which will absorb the spark from a direct-current magnet at 2¼ amperes, 9 000 ampere-turns, 115 volts, the circuit being closed with a strap key, operating an electric lock. C. S. R. (PENNA.)

In order to calculate even approximately the proper capacity for this application, it would be necessary to know (1) the total change of flux-linkages which occurs when the circuit opens; (2) the time taken by this change. Assuming that these quantities are known, the proper capacity can be estimated as follows:

(a) Find the voltage rise at the contacts by the formula—

$$E = \frac{(\Phi_1 - \Phi_2)N}{t} \times 10^{-8} \ldots\ldots\ldots\ldots (1)$$

(b) Equate the kinetic energy of the coil circuit to that of the condenser circuit as follows:

$$\tfrac{1}{2}\, C E^2 = \tfrac{1}{2}\, (\Phi_1 - \Phi_2)\, NI \times 10^{-7} \ldots (2)$$

(c) Substitute the value of E from (1) in (2)

$$\tfrac{1}{2}(\Phi_1 - \Phi_2)\, NI \times 10^{-7} = \tfrac{1}{2}\, C \left(\frac{(\Phi_1 - \Phi_2)}{t} N \times 10^{-8}\right)^2 \text{ or } C = \frac{10^9\, It^2}{(\Phi_1 - \Phi_2)N} \text{ farads, where}$$

N = number of turns, I = amperes, t = seconds and $\Phi_1 - \Phi_2$ = change of flux. The capacity thus found will be just sufficient to absorb the energy of the spark without appreciable voltage rise at the terminals. If the maximum safe voltage which the condenser will stand is known, this voltage may be inserted in place of E in equation (2) and the capacity C may be calculated by solving equation 2 numerically for C. In this way the smallest capacity is found which will absorb the energy without prohibitive voltage rise. The first method (substituting E from equation 1 in equation 2) gives in general very large capacities and practically no rise in voltage above the normal circuit voltage which is effective across the terminals when on open circuit. As the question gives no idea of the area of magnetic circuit, the average permeability or the time taken in opening the circuit, it is not possible to make even a rough estimate of the required capacity from the data given. P. T.

1125—Total Number of Demagnetizing Ampere-Turns—Please show how to find the total number of demagnetizing ampere-turns on the armature and the number of turns on each series field coil to balance same, in a 100-kilowatt, four-pole, 500-volt generator having a four-path armature winding with 500 turns; forward lead of the brushes is 10 mechanical degrees, and 0.868 of the armature current flows through the series field coils. Also find the total number of cross ampere turns. Has this generator four magnetic circuits to be considered when computing the back armature turns? I have used the following method in computing them:

Back ampere turns = 2(10/180 × ZI/4)
Z = total number armature conductors
I = total armature current

I am of the opinion that I should have multiplied by four instead of two. If my last statement is correct, please explain why it is only necessary to put one-half as many ampere turns on the field magnets to neutralize their effect. E. L. (VA.)

Computation of armature demagnetization is usually least confusing when compared with the conditions in a two-pole machine. The demagnetizing armature ampere turns of a two-pole generator are contained in double the angle of brush shift on both sides of the armature. (See article on this subject by R. H. Taylor, in the JOURNAL for Jan., '14, p. 65.) In the above instance, therefore, on the basis of two poles, the demagnetizing armature ampere turns would be calculated as follows:

Total armature turns = 500 ([illegible]).
Current per conductor = 200 ÷ 4 = 50 amperes.
Total armature ampere turns = 25 000.
Brush shift in electrical degrees = 10 degrees (same as mechanical degrees for two poles).
Double angle of brush shift = 20 degrees, one side of arm.
Double angle of brush shift = 40 degrees, both sides of arm.
Demagnetizing armature ampere turns = 25 000 × 40 ÷ 360 = 2 780 approximately, if machine were two pole.

For multipolar machines, however, the actual brush shift in electrical degrees is the product of the displacement in mechanical degrees by the number of pairs of poles. In the above instance, therefore, the total demagnetizing armature ampere turns equals $2 \times 2780 = 5560$, which checks with the method outlined in the inquiry, $2(10/180 \times ZI/4)$. The succeeding statement in the inquiry with regard to multiplying by four instead of two is incorrect. Cross demagnetizing armature ampere turns are the difference between the total and the demagnetizing ampere turns, viz., $25000 - 5560 = 19440$. The series field has to supply not only the demagnetizing effect of the armature but also the IR drop in the machine. The series turns cannot, therefore, be determined from the armature characteristics alone. R. H. T.

1126—Super-Heated Steam—Is it necessary that steam be in motion in order that it become superheated? G. N. G. (COLO.)

It is not necessary that steam be in motion in order that it become superheated. It is, of course, necessary that the steam be dry, otherwise the heat will serve only to evaporate the moisture and not to superheat the steam. We understand that "motion" means the passage of the steam through pipe, tubes, etc., and does not refer to molecular activity. M. C. M.

1127—Size of Cable—What size cable should be provided for a three-core, lead sheath, rubber covered cable run 1 300 feet underground in duct to two 750 k.v.a. oil cooled transformers supplying a three-phase, 40 cycle, 550 volt motor load? The voltage at the receiving end is 10 000 and the transformers are fully loaded. C. A. T. (MASS.)

With the understanding that this is a single triplex, rubber insulated, lead covered cable, delivering 1 500 k.v.a. to transformers and installed in underground ducts, under normal conditions, and assuming that there are no other power cables in adjacent ducts from which heat would be received, or which by their presence would prevent radiation of heat from the single cable mentioned, we would recommend a No. 3 B. & S. gage conductor; or if the load was not continuous at all times, possibly a No. 4 B. & S. gage conductor. There are so many questions involved in the heating effects of cables, that it is extremely unsafe to give a positive answer to any one question without knowing complete details. In this case the impedance drop in voltage does not enter into the problem because of the short run. R. E. D.

THE ELECTRIC JOURNAL

VOL. XI | OCTOBER, 1914 | No. 10

An Opportunity for the A. E. R. A.

Developments in the electric railway field have been tremendously active in the last three or four years. Apparently every designer and operating engineer has kept his brain working overtime trying to discover some new and better way of doing something that has already been done with more or less economy and satisfaction. The campaign for economy and efficiency led in the first place to a reduction of weights, and this has been the excuse for a great many changes in all parts of the rolling stock of electric railways. Car designs have been changed until some of the late ones look no more like the cars of a few years ago than the first safety bicycle looked like the old high wheel machine; and apparently the end is not yet. With so many new designs of cars being tried out, it is impossible to say what will be standard; if, indeed, there will be any standard design of car in another year.

Car trucks have been going through much the same evolution. With every effort made to lighten them, it has in many cases been necessary to adopt special grades of steel, and rolled and pressed sections that are economical only when used in quantity.

In motor control, the tendency has been away from platform controllers, even on small cars, and towards some form of remote control. Multiple-unit operation is being adopted more and more, and the the control has been simplified to such an extent that it is now in many cases cheaper to maintain than the platform controller. Many changes have been made tending to simplify, concentrate and lighten the control equipment. With certain standard parts as a basis, a great many special equipments differing in details, have been put out to meet the requirements of different railways.

The railway motor has been changed as much as anything. The early commutating-pole motors, perfect as were their records, have been supplanted by so many different types, that it is necessary for one to have an ever-changing encyclopedia with him at all times, in order to be able to keep track of them. There are now motors designed primarily to reduce weight; also high speed, low speed, field control, open and enclosed motors. Then there are motors for standard wheel diameters and motors for low wheels, motors with through axle cap bolts and motors with tap bolts, with and without axle dust guards, with and without armature spiders, with and without adjustable brush tension; box frame and split frame motors, with two-point and three-point gear case suspension, etc., etc. In short, the railway motor has been modified in almost every conceivable way.

It sometimes seems to the manufacturer of equipments as if every operator insists upon some special requirement. It may be some particular service condition or some space requirement, some special design of motor bearing or some peculiar arrangement of switch-board or control wiring. In any case, it is nearly always different in some respects from anything that has ever previously been built. Of course, this tendency is not all with the operating engineer. Manufacturers' engineers have performed their full part in this evolution. Each one, in endeavoring to out do the rest, has introduced new features that are calculated to meet "long felt wants."

There can be no question as to the progress that has been made in the art, but the net result is that there is now a great variety of equipments in use, very few of which would be duplicated in all parts if new equipments were purchased. This is fine business for the engineers, who are working toward the ideal, but it is mighty hard on both manufacturers and operators. The electric railway industry has been absorbing development charges large enough to keep a respectable army in the field, hoping that each change would result in a standard, but the fact is, the styles change so rapidly, that the manufacturers scarcely dare to put in a stock of anything for fear it will be obsolete in three or four months. However good it is, it may not meet the requirements of the latest fad. Manufacturers do not generally build apparatus at a loss, and the operators must pay.

The obvious remedy for this condition of affairs lies in standardization. But after 25 or 30 years of development we actually seem to be farther from standards than ever before, although every part of the equipment has reached a high state of perfection. The trouble seems to be that there are too many different individual opinions as to details and too little appreciation of the value of standards—not simply standards for any one city or system but standards for the whole country. Most cars are now made of steel. Standardization will mean everything for them, as a complete set of tools can be made that will permit relatively cheap production. The same may be said of trucks. Switch groups, reversers, master controllers, relays and all the other parts going to make up a control equipment can be enormously cheapened, if built

in large quantities without changes being continually made.

Now comes the pressed steel street car motor. This is an assured success if the motors can be standardized, but it cannot be produced in competition with cast steel frames, if every order has some special feature.

In this emergency the eyes of all turn towards the American Electric Railway Association, with a confidence born of past experience and a knowledge that the Association contains in its membership practically all the men who are capable of judging the merits of electric railway equipment.

Now what can the Association do? In the first place, it can back up the recommendations of the standards committee. The Engineering Manual recently published contains a great many standards and many recommendations for approved methods and practice covering a broad field. It represents an amount of labor that can be appreciated only by those who have done similar work. The Manual will be of great value if it receives the proper support, but it will take constant pressure to get the standards adopted. In some cases these recommendations have been rejected even by members of the standards committee themselves, when the application related to their own roads. There is a certain appreciation of the value of standards on the individual road, but the great advantage of one standard for the entire country does not seem to be properly appreciated. The record made by the manufacturers of automobiles shows what wonders in the way of cheaper production can be accomplished by sticking to one standard. These results could never have been obtained if every city or even every state had demanded some special features. The Association, of course, cannot adopt certain makes of motors, control, cars, trucks, etc., as standard, but it can do a tremendous amount towards standardizing practice. The great variations in styles of railway motors have already been mentioned, but they did not cover the range of ratings that is now necessary to meet the market demands. We look to the A. E. R. A. to crystalize the demand, so that a smaller number of designs will be needed. A recommendation as to standard practice, *properly supported*, should work wonders.

Similarly, the standardization of control practice could be effected. There are now many different ways of wiring cars, innumerable styles of train line jumpers, receptacles, junction boxes, master controllers, switchboards, lightning arresters, choke coils and other details of practice, the standardization of which has heretofore been impossible because there has not been sufficient concerted action regarding it.

The American Electric Railway Association is the organization above all others to undertake this work. It seems to be generally admitted that this country will have to face a tremendous rush of business in a comparatively short time. The best way to handle this is to build standard apparatus, and this can be done only by the active coöperation of the operating engineers. We must have "Safety First," but let us at least have "Standards Second." N. W. Storer

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Utilities from the Public Viewpoint

Without a full understanding and appreciation of the other man's point of view, the task of reconciling divergent opinions is made increasingly difficult. For example at the present time the public's point of view regarding utilities is that, in general, they have been exploited unfairly for the benefit of the insiders, that the public have been gouged and that now, by means of restrictive laws, commissions, etc., the public are going to get square. Of what avail to try to deal with a man in that frame of mind by showing him your books and telling him how good you are and asking him to please be "fair" and "let" you make a little more profit. He will think you "good" only because you have to be, because his Commissions have made you behave. You have to approach this man on an entirely different tack—show him that no matter how it was started your utility is not finished—never will be—no utility is or can be, because no community stops growing, and it is going to need more money to grow with than it has already held up to date; that restrictive laws have kept money out of utilities in New York State and elsewhere, are keeping it out, will keep it out more and choke industry, and consequently hold back the development of the towns served. That's going to hurt his business, touch his pocket, but if he waits to be shown, waits until his business really is hurt and his community stifled and then begins to try to do something, it is liable to be like trying to raise a crop of peaches from an orchard that has been struck by the blight. There are lots of towns that have been struck by the blight; those who would not let the railroads through or the trolleys in. They never get back to their relative positions. That's the sort of an argument that may meet his point of view.

As a matter of fact there are many thinking men who believe that our present attitude towards utilities is one of the most serious menaces to the continued progress and prosperity of our country. It is the swing of the pendulum from no regulation to over-regulation, from letting them do everything they please to not letting them do anything they want to. We are forgetting in our zeal that the very first people to realize the mistake will be those with money to keep the utilities growing—and who won't use it that way on the meagre chances of gain that our new laws permit—and the last people to realize the mistake will be the publi who, secure and satisfied in the conscious rectitude of having put a stop to over-exploitation, will disregard the wails of those hurt and wait to be hit on the head with the club of outgrown facilities. A friend of mine recently remarked that his father—eighty-eight

years old, still living—saw the first steam railroad built. We are accustomed to think of steam railroads as our oldest and best established utilities. All the others—gas, electric light, telephones, trolleys—are younger, very much younger. And here our whole vast, stupendous structure of modern utilities has come into being in the span of one single human life.

The test of virtue in a sound basic law is endurance. Right and wrong do not change. If such a law is good now it ought still to be good fifty years hence and ought to have been good fifty years or more ago. Now suppose that seventy odd years ago when that first steam railroad was started we had had the Interstate Commerce Commission and all our State Commissions and all our present laws, and had kept them up-to-date—does anybody think we would have all these utilities that we enjoy today? And without transcontinental railroads, and trolleys, and telephones and electric power where would Denver be? St. Louis, Chicago, Pittsburgh, New York—any of us? Oh! but,—says the Brandeis type of reactionary—hold on, we needed one set of laws to encourage infant development and an entirely different set, now that our utilities are developed—and that's just the fatal mistake—they are not developed, only started. Can we make the blind men see it?

CALVERT TOWNLEY

The Philadelphia Transportation Problem

The story goes that when the Czar of Russia was asked to indicate the route by which a railroad was to be built from Petrograd to Moscow, he drew a straight line on the map between the two cities. This is probably the simplest solution of a traffic problem on record. It was probably the most expensive and very likely not the best from an economic point of view. But an imperial will and unlimited resources made naught of obstacles and objections.

Were the monarch of the United States, the free and independent American citizen, in any center of population requiring rapid transit, to be asked the same question in relation to his residence and his place of work, he too would be governed by the axiom that a straight line is the shortest distance between two points. So also would all of his royal neighbors reply, and where there is a multitude of imperial wills, our way is for the majority to rule. Furthermore, perforce, expense and returns on investment are considerations, but the greatest single consideration is what the people need.

Consequently, when the city of Philadelphia came to solve its transit problem, its Director of City Transit asked the riding public a few simple questions, intelligently designed to bring out essential facts, combined the results with the proper factors and integrated the equation. Mr. A. Merritt Taylor's contribution entitled "The Solution of a City's Transit Problem" in this issue of the JOURNAL, which tells how it was done, is a remarkable example of logical analysis and will be eagerly absorbed by the profession and the public as well. Not only Philadelphia will benefit therefrom but other cities, large or small will be able to do so, if this magnificently simple yet wonderfully conceived and executed plan is adapted to local conditions.

JOHN J. GIBSON

Higher Direct-Current Voltages

The development and perfection of the commutating-pole series wound railway motor, together with the apparent possibilities of the mercury arc rectifier, seems to offer a broad promise of the successful introduction of much higher direct-current voltages in connection with railway electrification work than has heretofore been practicable or even possible. Until within recent years, the maximum direct-current voltage which could be successfully applied for tractive purposes scarcely exceeded 600 volts. With the development of the commutating-pole railway motor and its vastly improved commutating characteristics, it became possible to operate traction systems satisfactorily with a trolley voltage of 1 200 to 1 500 volts with two motors in series, with entire success.

A much more serious problem was met in providing suitable constant potential generating apparatus for supplying these higher voltages, although successful operation has been obtained with the current supplied through rotary converters and also through generators. In some cases the rotary converters or generators have been wound for 650 or 700 volts in themselves and operated two in series. In other cases they have been wound to produce the trolley voltage in one single unit. Similarly, 2 400 volt apparatus has been employed for heavier train propulsion, using motors wound for 1 200 volts connected two in series, and generators wound for a corresponding voltage also connected two in series. Installations of this type have been reported comparatively free from trouble, especially as regards the motors. The constant voltage of 2 400 is, however, somewhat difficult to provide by means of direct-current generators even when operated two in series, which arrangement is even at the best, rather a make-shift proposition.

Recently experiments have been conducted in which much higher trolley voltages were used in an experimental way than have ever been adopted in practice, mercury arc rectifiers being used as a means of obtaining the necessary constant-potential direct-current. Two comparatively small motors, operating in series, were given rigid tests on a trolley voltage of 7 000 volts, with promising results. It is to be hoped that an equipment of this type involving the use of a trolley potential of at least 5 000 volts will soon be put into practical use, even although it is to be used for demonstration purposes only. If it proves to be prac-

ticable to use a trolley voltage of 5 000 volts or more, which is certainly hoped will be the case, the use of direct current will become available for the heaviest form of propulsion, as at that voltage, or even perhaps at a somewhat lower voltage, it will be entirely feasible to collect from an overhead trolley the volume of current which will be required by heavy locomotives under the maximum conditions both of traction and of speed, while at the same time the high efficiency of the transforming stations, together with the fewer number required and the comparatively smaller 'attendance, will make the distribution of power to the locomotives or cars both highly efficient and economic. C. S. Cook

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Pressed Steel Railway Motors

The development of a pressed steel railway motor is the most notable contribution which the year 1914 makes to the electric industry. Pressed steel is coming into general use in a continually broadening field. Wherever structures require uniformity and reliability coupled with light weight, pressed steel must be considered, if the number of identical units required by the trade is sufficient to justify the tremendous expense of dies and tools.

Pressed steel is now recognized as the best material for car bodies and trucks. The adaptation of pressed steel to the motors is, therefore, the next logical step. In fact, with the growing tendency toward train operation in city service, pressed steel in motor construction, besides having all the good points of pressed steel in cars and trucks, offers advantages much more far reaching. Where a large number of motors are worikng together in a train, it is very advantageous to have motors with uniform characteristics, so that each motor will do its own share of the work. Differences in wheel diameters will invariably impose different loads on the motors, therefore the elimination of other variables is highly desirable.

Much has been done toward the reduction of differences between individual cast steel motors of a given type, but pressed steel motors are inherently of more uniform characteristics. The experience gained in the development and manufacture of pressed steel industrial motors by the Westinghouse Electric & Mfg. Company during the past several years, and the great success of this line of motors, led to the development of a pressed steel railway motor, as described by Mr. C. W. Starker in the present issue. The success of the first efforts along the lines of the development of pressed steel railway motors indicates that probably in another year, with the coöperation of the railway public, it will be possible to have such motors available for the market at least in one or two sizes. It will, of course, not be practicable to develop a pressed steel motor in any size until the market demand for such a size justifies the expense involved. The pressed steel motor may, therefore, introduce an element of all around economy, in that a given number of sizes may be agreed upon to meet market requirements, and thus become standard, which will eliminate the repetition of the enormous expense which has been incurred during the past several years through the development of many types, sizes and shapes of railway motors, all of which in the end tends to increase the costs of both the manufacturer and the user.

It requires considerable courage and great confidence in the future market for any manufacturer to tackle such a problem, particularly so since an analysis shows that an increased cost may be expected for a long time to come, and that the justification for the greater expense in development rests entirely in securing greater operating economy, first by reduction in weight, without increasing armature speeds; second by more uniform strength of parts and a greater ease of repairs.

We believe that this form of motor offers to the street railway field an opportunity for effecting a reduction in their maintenance and operating costs, but this opportunity will involve a higher initial cost.

M. B. Lambert

Improved Control Equipment

The possibility of converting standard "K" control equipments to meet present-day requirements is certainly a valuable development in railway progress. The flexibility of the new control equipment described in the article by Mr. McIver in this issue, lends itself to a wide and varied application. Its performance has more than met the expectations of its designers.

Due to conditions on many roads, brought about years ago, for which the present managers are in no way responsible, it is difficult for them to discard existing obsolete equipment and finance the installation of new up-to-date apparatus, even though their present maintenance costs may be excessive. Therefore, the equipment described will be a boon to those operators since, by the addition of a "PK" head, an old equipment can be brought up to a high point of efficiency without the necessity of discarding existing apparatus.

The removal of all heavy current carrying parts from the car platform is also a logical "Safety First" step. The possibility of train operation during rush hours and special runs is the next step towards this goal and when, in addition ,the operation of trains enables crowds to be transported in such a way as to acquire a satisfied public and, furthermore, avoid interference with the schedule speed, no further advancement in the way of approval seems possible.

The extended and successful service trial outlined in Mr. McIver's article is an excellent indication of the success of this new scheme. Judging by the satisfactory operating results secured, the application of this form of equipment on many roads seems assured.

B. W. Stemmerich

The Effect of Federal Legislation Upon Public Utilities

G. E. Tripp
Chairman, Board of Directors,
Westinghouse Electric & Mfg. Company

During the last very few years there has been a remarkable development in high tension transmission systems and a rapid linking up of local electric light and power markets to one central source of supply furnished by steam power stations or water power developments or both. This movement has been heartily approved by sane observers as being desirable from the standpoint of sound public economics and it has proved to be a profitable field for energetic and far-seeing experts in the public utility work.

G. E. TRIPP

It has been possible to build up many transmission companies as private corporations by confining their activities purely to the sale of wholesale power and distributing it through local public service companies, and the greater freedom which has thus been allowed the promoters in the amount and character of capital issued has permitted attractive offerings to the public and greatly stimulated the flow of capital into these enterprises.

Where it has not been possible to maintain the transmission company as a private corporation, the holding company practice has been followed, and through that method financial offerings have been made attractive. A great deal has been said concerning holding companies which control public utilities and the opinion is practically unanimous that a company which holds the securities of physically connected subsidiaries rests on a sounder foundation than a holding company controlling scattered properties. While this is undoubtedly the case, considered from an abstract point of view, the pending anti-trust measures at Washington threaten to shift the balance of favorable conditions by creating a situation which will render many physically connected properties subject to embarrassing and menacing legislative conditions and prohibitions. That is to say, the ideal development of the electrical industry consists of large central sources for the generation of energy and wide-spread transmission lines conveying the current to the diversified industries of as large an area as possible and, as in practice these areas are not always marked out by state lines, a great many of the centralized power enterprises will become engaged in inter-state commerce and may be directly subject to the proposed inter-state trade commission bill and perhaps to the Clayton bill. A full analysis of these bills cannot be given within the limits of a short article, but a few of the proposed enactments which will affect inter-state power companies are as follows:—

A company cannot engage in inter-state commerce until its issue of capital has been approved by the inter-state commerce commission.

It will be unlawful for it to own a whole or any part of the capital stock of, or control in any other manner, one or more corporations carrying on competitive business.

It cannot engage in inter-state commerce if there is a person upon its Board who is a Director or Officer in a competitive inter-state company.

If any person shall be injured by a violation of some of the sections of the inter-state trade commission act, he may recover three-fold damages.

If the inter-state sale of electrical energy should bring a power company under the provisions of the Clayton bill, then it would be affected by the "unfair business practices" provisions which among other things forbid discrimination in prices, and requires that the buyer shall not handle or use the product of a competitor.

The above are only a few of the things which would have a direct effect, provided inter-state power companies are held to be engaged in inter-state commerce. Nor would the situation be improved if they were not so held but were deemed to be common carriers and subject to the control of the inter-state commerce commission.

It is not to be presumed that these obstacles will prevent the proper development of the distribution of electrical energy in this country, the benefits of which have only begun to be realized, but the menaces are serious enough to remind the busy men, who are projecting these enterprises, that it is not enough for them to know that the concentration of power supply avoids enormous economic waste and creates a new factor in civilization, but that the public must also be made to know it and to realize that the proposed anti-trust legislation ought to be modified with respect to this important new system of transmission of electrical energy which will be hardly less far-reaching in its benefits than the telegraph, long-distance telephone and trunk line railroads.

Purchased Power for Electric Railways

Wm. C. L. Eglin
Vice-President, The Philadelphia Electric Company
Past President, National Electric Light Association

The purchase of power by urban or interurban electric railways has frequently been discussed before engineering societies and in the technical press; and it is a policy which has been adopted by the progressive managements of railways in many sections of this country. Its advantages are manifold; two of which, "Economic Advantage" and "Reliability of Service," are here covered briefly.

WM. C. L. EGLIN

ECONOMIC ADVANTAGE

The purchase of power releases the railway company from the large investment which it would otherwise have to make in power houses, equipment and apparatus, and reduces the responsibility of its operating force; thus enabling the management to devote its entire attention to building up the particular business of the railway; viz., transportation. In the management of any large undertaking, it is an axiom to purchase any material or apparatus in the open market in preference to manufacturing it, provided this can be done at the same or less cost. Therefore, the question that must be answered, is:—Can the urban or interurban railway company purchase power at the same or less cost than by generating it in its own power houses?

Electric power is generated in large quantities either by hydro-electric developments or by steam-electric plants. The cost of power depends upon the initial investment, the efficiency of equipment, the cost of fuel and other supplies, the labor cost, and upon the maximum demand for power and its average use. Hydro-electric developments are limited to certain localities, and it is not the intention to treat of these. Economical plants of the steam-electric type depend upon a reasonably good supply of fuel at a fair cost; an abundant supply of water for condensing purposes; and reasonably pure water or boiler feed. The efficiency of the steam turbine being higher than that of the steam engine, some type of steam turbine is universally used in power houses of any magnitude.

At the time of the introduction of the street railway systems, 500 volts direct current was required for this service. This voltage was not available from most of the electric supply companies; and, as the latter companies also had difficulties then in financing their requirements to take care of the rapid increase in their business, no effort was made by them to interest the railway companies in the purchase of power. Later, as these railway systems were expanded to cover larger areas, requiring a wide distribution of power, the use of a number of generating stations became necessary; and still later, with the advancement in the art of generating electric power by the use of high-voltage alternating current apparatus and the distribution of the alternating current to sub-stations where it was converted into direct current of the voltage required for the operation of the railway system, more economic results were obtained.

It will thus be seen that, to-day, the generating stations and sub-stations required by urban or interurban railways are practically the same in equipment as those required by the electric supply company. The railway companies have been forced, in many cases, to abandon the old direct-current generating stations, either using part of them as sub-stations or building new sub-stations in more desirable locations. In order to effect a reduction in their power costs, these companies have also been forced to an additional investment for installing modern apparatus for the generating of high-voltage alternating current at frequencies of 25 to 60 cycles.

These conditions govern the power houses of both the electric supply company and the urban or interurban railway company; so that the investment costs, if based on the same efficiency, are the same for either company. Therefore, the electric supply company is under the same fixed charge covering investment, maintenance, depreciation, etc., as is the railway company. The railway power house must be designed to meet the conditions of its maximum load. Its output, however, depends upon its average load. The electric supply company is able to take over the additional railway load; which tends to improve its average load or raise its load factor, and in this manner reduce its costs. It is logical to suppose that the electric supply company can furnish power at the same cost as the railway company can produce it and with a margin of profit, depending upon its success in improving its load factor, due to the other loads connected to its system. It cannot be disputed that the electric supply company must be able to furnish power to the urban or interurban railway company at the same cost as the railway company can produce power itself.

Very rapid advances are being made in the electric art, and the electric supply company can afford to discard obsolete apparatus and add more efficient and improved apparatus, so as to secure a reduction in its cost for generating electricity. This would not

be considered justifiable in a single, small individual power house, or even in large individual plants. The railway company knows that in purchasing power, it will always be able to obtain the benefits from the improvements in the art, without making a large additional investment.

The urban or interurban railway business in any territory rarely attains the saturation point, for the reason that there is almost invariably a constantly growing population in the district which it serves. The needs of the community constantly necessitate better facilities; thus requiring, on the part of the railway company, further investments for extensions and improvements. In the purchase of its power, that portion of its investment has been eliminated; in this way enabling a more rapid development of the railway company's territory.

RELIABILITY OF SERVICE

Another advantage in the purchase of power from the electric supply company, is reliability of service. The conditions governing reliability of service may be said to be generally the same; i. e., high-class apparatus, which requires skilled attention; and a well-trained organization. Continuity of service is safe-guarded, in the most careful manner, by all well-managed public electric supply companies, as it is the most essential feature of the success of their business. Greater precautions in this connection can be taken by the electric supply company than would be warranted or justified by the individual power house. To maintain the same reliability as is required from the electric supply company, the reserve in the individual power house must be larger in the case of the railway company, as it must have on hand sufficient reserve to take care of the disablement of at least one unit, and possibly must have additional spare units to take care of any extraordinary demands. Owing to its larger plant and the varying demands upon it, the electric supply company has a greater factor of reliability for any one individual consumer. The personnel of the electric supply company is at all times alert and keenly interested in maintaining good, reliable servce, and its employes may be classed as specialists in this one branch of the industry. They are seeking, upon every occasion, to further improve the efficiency of the apparatus and its operation so as to reduce the costs and effect better service.

The concentration, in the electric supply company, of all of the power requirements in a given area, leads to economic advantages in the reduction of investment and plant, the equipment of its plant being designed to meet average demands instead of maximum demands as in an individual power house. Therefore, it is a safe, sane and progressive policy to purchase power in any territory in which an organized electric supply company exists.

The Pacific Electric Railway System

G. B. KIRKER
Los Angeles Office,
Westinghouse Electric & Mfg. Company

WITHIN the last twenty years the electric interurban railway system in the Los Angeles district has grown from a single line fourteen miles long, connecting Pasadena and Los Angeles, to one of the largest interurban systems in America, by which practically all the surrounding towns within a radius of 50 miles are connected to Los Angeles. This system, which is now the "Pacific Electric," is the result of a number of consolidations whereby all the interurban lines operating out of Los Angeles and the street railway lines operating in all the surrounding towns have been brought under one head. Since the consolidation numerous extensions have been built. The Pacific Electric has been one of the prime factors which has caused the phenomenal growth of Southern California. At the time the single line was operating between Los Angeles and Pasadena the population of Los Angeles was approximately 50 000. At present it has grown to over 500 000.

By referring to Fig. 1, it can readily be seen how the lines reach out in every direction and how great is the amount of territory served. The system is divided into four divisions. The northern division includes the lines serving the territory lying to the north and northeast of Los Angeles. This is the section of beautiful suburban towns and villages and small ranches scattered at the foot of the Sierra Madre mountains. The eastern division is composed of the lines operating in and around San Bernardino, Redlands and Riverside. The southern division includes all lines running to the south, southeast and southwest of Los Angeles. This is a section of large ranches, large suburban towns and several popular beach resorts south of San Pedro, which is the seaport of Los Angeles. The western division includes all lines running west. This territory includes all of the beach resorts from Redondo north, also La Brea oil fields and several beautiful suburban towns.

SERVICE CLASSIFICATIONS

The passenger service is city, high speed suburban and interurban. The freight service is composed of express and fast freight. The mail service is quite extensive.

The company operates a local suburban service over the regular interurban tracks out of the city and, to avoid congestion on the northern and southern divisions, certain sections are four-tracked. The suburban service is operated over the two outside tracks and the two inside ones are reserved for the high-speed interurban cars.

There is a high-speed interurban service between Los Angeles and all of the larger towns surrounding, the longest run being approximately 60 miles.

CAR EQUIPMENT

For maintaining the passenger service there is a total of 589 motor cars, consisting of several different classes. The "1 000 class" cars are equipped for 600 and 1 200 volt operation. The "800 and 900 class" cars are equipped with Westinghouse A.B. control. Some of these cars are equipped with four Westinghouse No. 76 motors and the others are equipped with four Westinghouse No. 112 motors. These cars are used for the high-speed interurban service on all lines except the Pasadena Short Line. The "700 class" cars are operated on the Pasadena Short Line. The "550 class" cars operate on a mixed suburban and interurban line where high maximum speed is not necessary on account of the numerous stops. The "500 class" cars are equipped with Westinghouse A.B. control and four No. 306 Westinghouse motors. These cars are in very much the same service as the 550 class. The "400, 300, 170 and 100 class" cars are used chiefly in the city service.

THE LOS ANGELES TERMINAL

The main passenger terminal of the Pacific Electric system in Los Angeles is at Sixth and Main streets. This is the terminal for all lines except the western division, which is at Fourth and Hill streets. At San Pedro street the northern and southern division traffic separates. The interurban trains per day operated in and out of Los Angeles are as follows:—

	No. of Cars	No. of Trains
Northern Division....	1 098	800
Southern Division....	598	424
Western Division......	566	395
Total............	2 262	1 619

TRAFFIC CONDITIONS

The reason for the enormous passenger traffic of the Pacific Electric is due to a number of causes. First, there is a great deal of suburban travel, people with their business interests in the city, living outside of Los Angeles at the numerous beach resorts, such as Santa Monica, Ocean Park, Venice, Redondo, Long Beach, Newport and Balboa. The residents of the surrounding towns come to Los Angeles to do their shopping and transact business in general, so that Los Angeles is practically the commercial center of all this territory. There are numerous pleasure resorts and places of interest which attract a great tourist trade. The Mt. Lowe trip is one of the most famous in the United States.

The climatic conditions of Southern California are such that most every one wants to live in the open as much as possible, consequently people have built their homes so as to have plenty of room around them.

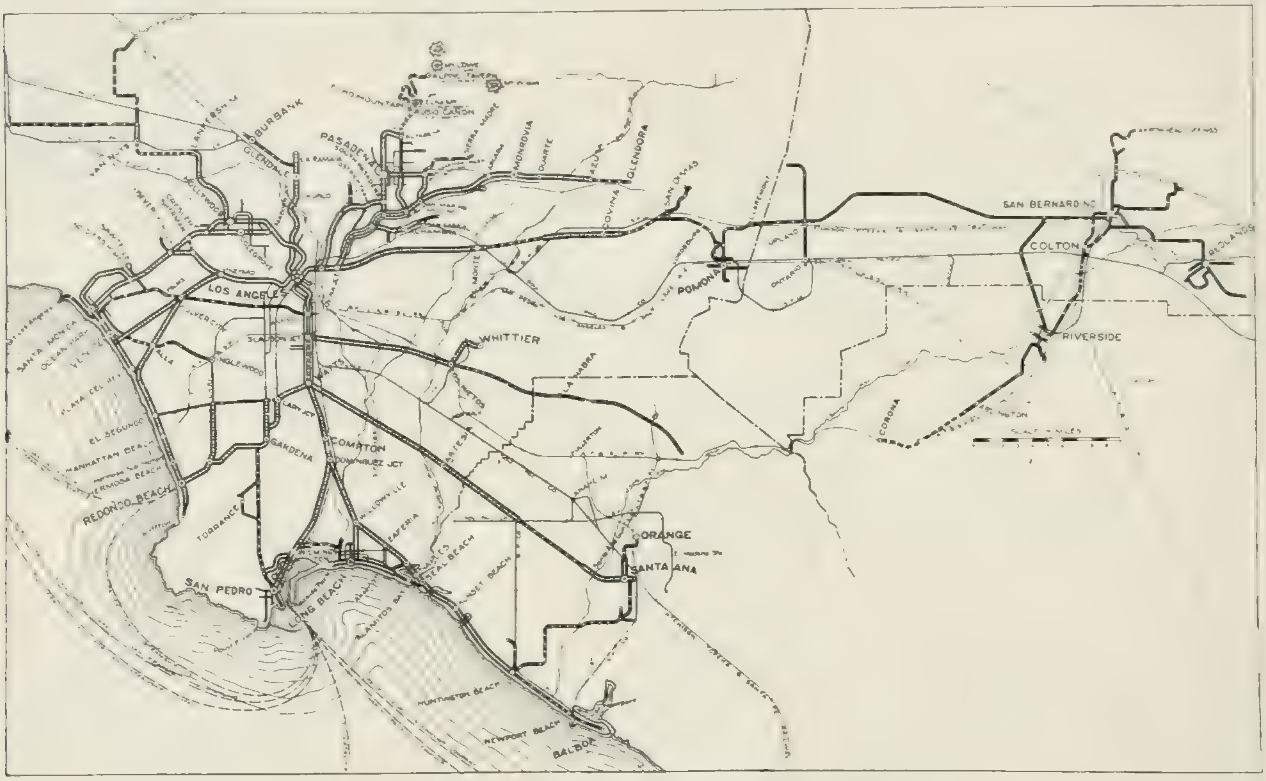

FIG. 1—MAP OF THE PACIFIC ELECTRIC RAILWAY SYSTEM

This necessitates going out from the city proper and increases the traffic of the railway company.

FREIGHT EQUIPMENT

While the Pacific Electric is known to the people in general as a vast interurban passenger system, it does an enormous freight business, totalling 39 954 903 ton-miles per year. There are eleven 60-ton locomotives for operating on 600 and 1 200 volts, and in addition, 32 switching locomotives. These locomotives, while they are designed as switching locomotives, are used also in regular freight service. For car equipment, there are 25 express cars, 16 combination passenger, express and mail cars, 13 service cars for line and general maintenance work and 1 145 freight cars. The latter include flats, stock, beet, oil and dump cars and gondolas. The total freight car mileage for the year ending June 30, 1914, was 3 614 732 miles. The freight handled by the railway company consists of fruit, general merchandise, rock, oil, beets and lumber.

FIG. 2—TRAIN OF HIGH-SPEED INTERURBAN CARS, SAN BERNARDINO LINE
Equipped with 600-1 200 volt equipment, ALF control and four Westinghouse 333-A-2 motors per car.

FIG. 3—60 TON LOCOMOTIVE OPERATING IN REGULAR FREIGHT SERVICE
Equipped with 600-1 200 volt control and four Westinghouse 308-D-3 motors.

TRACK AND ROADBED

The track is standard gauge and on all interurban lines 70 lb. rails are used. The ballast is chiefly gravel or crushed rock, but in some sections dirt and sand are used on account of local conditions. Most of the track is oiled to eliminate the inconvenience of dust. A large portion of the road is double tracked and parts of the northern and southern divisions are four-tracked.

The total mileage of the road is 1 032, single track equivalent. The rails are bonded, the work being done with an electric bonding machine.

OVERHEAD CONSTRUCTION

The accompanying illustrations will give a good idea of the overhead construction. Single-pole construction has been adopted on most of the lines except over the four-track sections, where the span construction is practically necessary. Most of the overhead construction installed within the last year or so has been of the standard catenary type single-pole construction, and a great deal of it has been insulated for 1 200 volt operation, as the company intends to operate most of the long interurban lines at this voltage. At present the entire system is operated with 600 volt line voltage, except about 20 miles of the San Bernardino line, which is now being operated at 1 200 volts. It is intended later to have the 1 200 volt zone on this line commence at Covina Junction, where it leaves the main line, and extend it to San Bernardino, and other lines will be modified later on. The catenary is so

constructed that pantograph trolleys can be used, but at present all cars are operated with wheel trolleys.

Within the last few years the company has been installing the latest type automatic block signals furnished by the Union Switch & Signal Company on all divisions, and within the near future the entire system will be protected by these signals.

FIG. 4—MAIN STREET ENTRANCE TO PACIFIC ELECTRIC TERMINAL AT LOS ANGELES

POWER DISTRIBUTION

Power is purchased from the Pacific Light & Power Company and the Southern California Edison Company, and is transformed in the various sub-stations by means of motor-generator sets to the trolley voltage. There is a total of 43 000 kilowatts capacity in motor-generator sets. All of the sub-stations are 600 volt except No. 23 and No. 24, where 1 200 volt machines are installed. The average input into the system is 13 100 000 kw-hrs per month. The peak load for the system is approximately 32 000 kw. The company has four portable sub-stations which can be sent out to any section of the line on which traffic conditions or accidents require additional power.

FIG. 5 FOUR-TRACK SECTION OF SOUTHERN DIVISION

SHOPS AND CAR HOUSES

The main shop and car house for the system is located at Los Angeles. There is a shop and car house located at Sherman, where light repairs and inspection are done for cars on the western division, and one at Pasadena for housing and light inspection for the cars on the Pasadena Short Line and the city cars operating in Pasadena. At Redondo there is another car house which serves as an inspection shed also.

At the main Los Angeles shops all work incident to the maintenance of rolling stock and motive power for the Pacific Electric system is carried on, and also practically all of the machine work, such as special work for the track. The maintenance of the equipment is very thorough, and not only are the cars equipped and painted and cleaned, but the electrical and brake equipment are kept in first-class condition. The organization of the inspection and maintenance is of the highest class and the result is that the car failures are few. The inspection is carried out on a mileage basis, so that each car is inspected once every thousand miles and a more rigid inspection is given every 10 000 miles, and every 50 000 miles there is a general overhauling.

FIG. 6—PASSENGER CAR FOR CITY SERVICE
Equipped with H. L. control and four No. 327 Westinghouse motors.

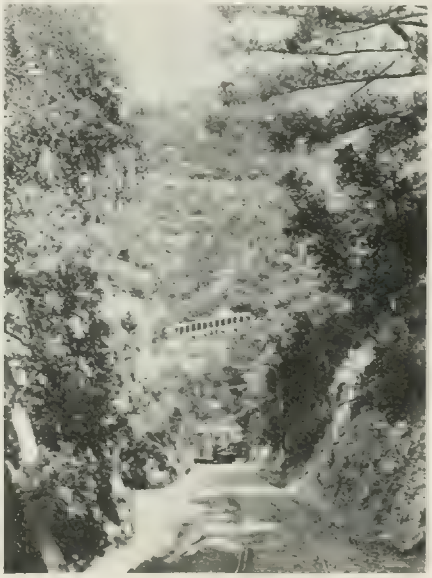

FIG. 7—MT. LOWE LINE
Showing how the line winds up the mountain.

The Electrified Hoosac Tunnel

L. C. Winship
Electrical Superintendent,
Boston & Maine Railroad

FOR THIRTY-SIX YEARS prior to the spring of 1911, the trains on the Fitchburg Division of the Boston & Maine Railroad were drawn through the Hoosac Tunnel by steam locomotives. During the early part of this period, the traffic handled was comparatively light and the tunnel, lighted by electricity, was featured in the advertising literature of the Company. As time went on, however, the number of trains increased, the electric lights grew dim and finally were discontinued and the tunnel became a thing feared by operating men and shunned by the traveling public. Each succeeding year brought with it increasing traffic and worse conditions and in 1910 the situation became so critical as to demand the use of electricity as a motive power. On May 27th of the following year, the electrification was an accomplished fact.

L. C. WINSHIP

For several years prior to the electrification, the freight business on this division was handled largely with locomotives developing a tractive effort of 33 000 pounds, the train loads being limited to 1 300 tons eastbound and 825 tons westbound, these limits being fixed by grades which existed at other points on the division. While the grade in the tunnel was but 26.4 feet to the mile, the rail conditions were exceedingly bad and so much difficulty was experienced in making the run that helping engines were provided for trains in both directions. The size of these helping engines was gradually increased from those developing 25 000 pounds tractive effort, in use in 1895, to oil-burning Mallets of 66 000 lbs. tractive effort, in use in 1910.

Occasionally an engineman, if conditions were at all favorable, would undertake the run through the tunnel unassisted, but many of the men were so affected by the difficulties of the movement, both real and imaginary, that they were unwilling to make the attempt alone. Nor was this fear without foundation. In many instances, enginemen and trainmen had been so overcome by the smoke and gas as to require hospital treatment. The rail condition was so bad that it was no uncommon thing for an engineman to place a broom handle against the tunnel wall in order to determine whether or not his locomotive was moving. In one instance an engineman of a passenger train was so deceived by the sound of the exhaust and the motion of the locomotive, that he allowed the driving wheels to slip until such time as he was signaled from the baggage car by an official who had discovered that the train had come to a stop. So long had this slipping continued, that the rails were worn practically through the head and the tires loosened on all of the driving wheels.

The movement of trains through the tunnel was controlled by operators stationed in signal towers located at each portal and the four and three-quarters miles of track in each direction were operated as a single block, there being no signals in the tunnel aside from certain location markers. Passenger trains moving in opposite directions were allowed to occupy the tunnel at the same time, and a similar rule was in force with respect to freight trains, but a freight train was not allowed in the tunnel at the same time as a passenger train. This method of operation, together with the necessity of providing helping engines, resulted in a congestion of freight trains at both portals and consequent delay to traffic. Long third tracks were provided near each portal for the accommodation of these waiting trains and to such an extent were they used that the one at West Portal became known as the "Overtime" track.

The movement of passenger trains was attended with great discomfort on the part of the passengers, for in spite of the closed windows and ventilators, the smoke and gas would enter the coaches to a very marked degree. The service was also very severe on the equipment, the coaches becoming so covered with moisture and soot on a single trip as to require the cleaning of the hand-rails and windows. The track maintenance was very difficult and exceedingly expensive. The trackmen and miners were unable to average more than two hours of work out of ten, the smoke during much of the time being so thick as to make their torches entirely ineffective. Consequently large gangs of men were required. The life of the 80 pound rail was but three and one-half to four years, due to the corrosive action of the moisture and gases and the abrasion which resulted from the use of large quantities of sand. The corrosive action was especially marked at the point of contact with the cross tie, spikes and tie plates wasting almost entirely away during the life of the rail.

Today one may stand at the center of the tunnel and see daylight at either portal. Trains weighing 3 200 tons are moved with ease and dispatch, and three of them may at one time occupy the same track between the portals. The "Overtime" track remains but the peculiar designation is obsolete and the track is once more known by its number. Passenger trains

move through the tunnel with doors and windows open, and on a hot summer day the cool air comes as a positive relief. The maintenance force, greatly decreased, get in a full day's work and the men are recognizable as they emerge from the tunnel at its close. The 100 pound rail gives evidence of a life of ten to twelve years and an increased life of the cross ties is expected. Such in brief is that which has been accomplished by the electrification.

In the electrical operation of the tunnel zone, 25 cycle single-phase current at 11 000 volts is received at the western portal and is there distributed to the various sections of the line, this distribution being in charge of a load dispatcher located in the signal tower. Such sectionalization of the lines as may be required at the eastern portal and at North Adams is attended to by men who are regularly employed in other capacities. On the approaches to the tunnel, the electric locomotives are used as helpers, the steam locomotives then being drawn through the tunnel with their trains. Steam assistance is given the electric locomotives on

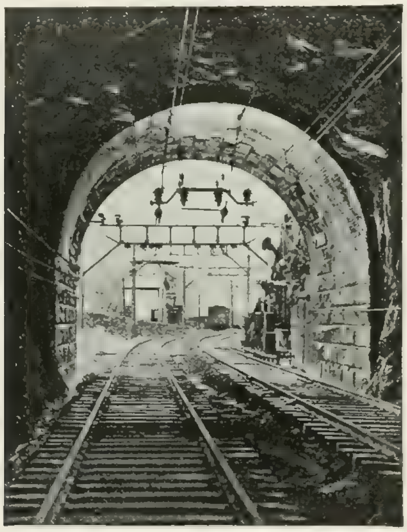

FIG. 1—VIEW LOOKING OUT OF THE EAST PORTAL OF THE TUNNEL

both freight and passenger trains during acceleration, this assistance being discontinued at such time as to allow the steam locomotive to enter the tunnel without the emission of smoke. This method of operation materially decreases both the running time of the trains and the load on the generating station.

The train movement during the years of 1911, and 1912, just subsequent to the electrification, was practically the same as that for a similar period during 1909 and 1910, but the addition of the block signals, which the electrification made possible, practically doubled the capacity of the tunnel and thus removed the limiting conditions which were very closely approached in 1909. In a number of instances during the busy season of 1911 and 1912, over 60 freight trains were handled through the tunnel in a single day. This number together with the passenger and light locomotive movements brought the total for the day up to about 100, or practically one movement for each 15 minutes, a number which would have been impossible with steam operation. This increased freedom of train movement is clearly evidenced by a comparison of the overtime charge for similar periods of steam and electric operation. In October 1909 there was paid for overtime on the western section of the division, $4 201. In October 1911, there was paid for similar service, $477. Practically all of this overtime resulted from delays attendant upon the movement of trains through the tunnel. The tunnel is no longer the cause of overtime charges.

The motive power equipment comprises five locomotives, four of which must be available for service at all times during the day. The fifth locomotive is reserved between 6 A.M. and 5 P.M. for inspection and repairs. Eight engine crews are assigned to the electric service and this number is ordinarily sufficient to handle the business satisfactorily. One or two extra crews have been added occasionally for short intervals. In order to meet the changed conditions which have been recently brought about by the running of numerous double-headed steam freight trains, it has been customary to operate two electric locomotives in multiple as a unit.

At the time when the locomotive equipment was purchased it was thought that the electrical operation would be immediately discredited in the mind of the traveling public if the passenger trains were not moved through the tunnel as rapidly as had been customary with steam operation. Consequently the gear ratio of two of the five locomotives was made such as to permit speeds up to 55 miles per hour, with a tractive effort of about one-half that of the other three locomotives. Soon after the operation began however, it was apparent that the traffic passing through so short an electric zone could be handled most satisfactorily with all locomotives having the same characteristics, as it would then be possible to use each helper in its turn, every locomotive being available for either a passenger or a freight train as the case might be. As no objection had been raised to the slightly longer time taken by passenger trains when drawn by the freight locomotives having a speed limit of 30 miles per hour, it was decided to change the gear ratio of the passenger locomotive to that of the freight type. This change was made during the summer of 1912.

Since the movement of the first steam train in February 1875, a heavy deposit of finely divided carbon has gradually accumulated on the walls and roof of the tunnel. During the period of steam operation there was always sufficient moisture present to dampen the carbon and keep it practically quiescent. After two or three months of electrical operation, however, the moisture disappeared and the carbon was left free to move with any current of air which might disturb it. Large quantities of this dust became entrained with the ventilating air supplied to the main motors of the electric locomotives and frequent

insulation failures resulted. Not only was this dust troublesome on account of its abrasive and conductive qualities, but its inflammability under certain conditions contributed largely to the destruction of the motor insulation.

The rate of accumulation of this dust has been such as to make necessary the dismantling of the motors for thorough cleaning after a service of about 24 000 miles. Modifications to avoid trouble due to excessive dust have been tried on three armatures and the results which have been obtained are such as to warrant their adoption on other armatures as they be rewound. A change has also been made recently in the main circuits of the locomotives which promises to prevent in the future much of the serious trouble which has been experienced from this carbon dust. The auto-transformer has been made a two circuit transformer and the main and auxiliary motors are now on the closed secondary circuit. This arrangement, with the addition of ground detectors, not only tends to prevent failures by removing the greater part of the strain on the insulation, but it also provides a means of detecting the presence of incipient breakdowns which may be located and repaired before they lead to extensive burn-outs. The quantities of this dust which have been found in motors recently overhauled, have been somewhat less than that previously noticed and while this evidence may not be conclusive, it seems to show that tunnel conditions in this respect are improving.

FIG. 2—TYPE OF OVERHEAD CONSTRUCTION USED

During the warm summer months, the moisture which is drawn into the tunnel with the ventilating air, condenses in large quantities on the wires of the overhead structure. This moisture combines with the sulphur emitted in gaseous form by the steam locomotives and the acid which results from this combination at once attacks the copper. The dust and soot mixes with the products of this corrosion and a heavy paste, decidedly acid in nature, is built up on the trolley wires. The pantagraph shoe in its movement along the wires scrapes off a large quantity of this deposit and distributes it over the roof of the locomotive and all of the apparatus located thereon.

The trolley frames, roof plates, air reservoirs and piping suffer severely from the action of the acid and much thought and labor have been given to the matter of their protection. The trolley frames have been painted about once every three weeks, with an underfinishing black varnish, but the life of the steel tubing has been short in spite of this attention. A satisfactory protective coating for the roof plates must be able to withstand not only the action of the acid but the foot wear of the maintenance men, and considerable difficulty has been experienced in obtaining a coating of this nature. An asphalt paint was given an extensive trial, but was discarded on account of its tendency to soften in hot weather and its apparent lack of acid resisting qualities. At present fairly good results are being obtained from the use of two coats of blue lead and one of structural green paint.

Not only does this paste attack the apparatus on the roof of the locomotive, but it combines with the water which falls during a heavy rain storm and a solution results, which provides excellent conditions for short-circuiting the pantagraph trolley insulators. These short-circuits are not confined to flash-overs from the metal insulator cap to the roof, but frequently follow the drip from the lower trolley frames to the roof and air pipes. During the early part of the operation, many of the short-circuits were started by the water which ran from the insulator shield directly to the metal roof of the locomotive. In order to divert this water and to lengthen its travel, a wooden platform treated with insulating paint was placed under the insulators which carry the pantagraph trolley base. This additional insulation has undoubtedly decreased to some extent the number of flash-overs, but in spite of the frequent painting its surface soon takes on a conducting film which under certain conditions will start an arc. This fact was recently illustrated on a locomotive which had been standing in the shop yard exposed for several hours to a fine rain. One pantagraph was against the trolley wire and the other was in the down position. Both were alive. The flash-over took place between the lower frame of the trolley which was down and an adjacent air reservoir and an angle iron on the roof. The burn on the reservoir was twelve inches from that on the trolley frame and the one on the angle iron was two inches further away. The paint on the wooden platform was slightly scorched but there was no indication of the passage of any great amount of current over this surface.

The operation of the tunnel has been marked by the complete freedom from electrical failure of the 300 000 volt double insulation. The stranded copper messenger has failed in one instance under conditions which would indicate a diminution in cross-section due to the corroding effect of water which was continually dropping upon it from the roof. At another time, the messenger and trolley wires were completely severed by the arc which resulted from contact between the

trolley construction and a high brake staff on a moving car. The removal of the strain from one side of the insulator brackets which were adjacent to the break, resulted in a slight distortion of these particular brackets, but their alignment was readily restored by the repair of the wires between them. The fact that a line failure of this nature affected only two of the brackets, speaks well for a type of construction which supports the two lines of catenary, each four and three-quarter miles long without the aid of intermediate anchors or dead ends.

The corrosion of the catenary construction previously mentioned, has not as yet progressed far enough to materially weaken any of the component members, except in the case of the bronze double catenary hanger. This particular hanger is so designed as to permit of a certain amount of flexibility of the running wires, the flexibility being obtained through the movement of the lower part of the hanger upon the hanger rod. The rod has failed at the point of this movement and it is probable that the mechanical wear has contributed to the failure. A re-design of the hanger which would provide for an increased cross-section at

FIG. 3 REPAIR AND INSPECTION EQUIPMENT AT BARN

the lower end of the rod, would undoubtedly eliminate much of this trouble. Notwithstanding the fact that the advance of this general corrosion is not particularly rapid, it has nevertheless been viewed with considerable concern and a number of suggestions have been made with reference to the use of a protective coating. In October of 1912, a coating of tallow was applied to about 1 000 feet of the trolley and messenger wires over the eastbound track at a point near the ventilating shaft, these wires having been previously cleaned with a stiff wire brush. Upon an examination of this section, which was made in July of the present year, the upper side of the trolley wires was found to have retained the original coating to a large extent, and this surface was practically as smooth as when the coating was applied. Much of the tallow, however, had disappeared from the sides of the trolley wires and here a slight amount of incrustation was found. The results of the experiment which have thus far been obtained are not conclusive and further observations will be made from time to time. The cast iron fittings which were used in the line construction were originally protected by a coating of paint having a large rubber content. This soon proved to be ineffective and late in the spring of 1912, these fittings were thoroughly cleaned and given a coating of an asphalt paint. There is at present a certain amount of corrosion in evidence, but it is not of such a nature as to require attention for another year.

The movement of the steam locomotives through the tunnel results in a gradual accumulation of soot on the surface of the insulators. While this accumulation has not as yet caused a flash-over, it is nevertheless thought advisable to remove it about once a year. The soot which collects on the insulators which are at some distance from the tunnel portals, remains soft and is easily removed with dry cotton waste, but on the insulators which are near the portals, it takes the form of a hard glaze which adheres very closely to the porcelain. A mixture of kerosene and ashes applied with cotton waste has been successfully used on these particular insulators.

Micrometer measurements of the trolley wires taken at a point where the water is falling upon the wires in such a way as to keep them clean, show a decrease in vertical cross-section of about 0.027 inch during the three years of service.

An inspection of the overhead construction is made once a week from the line maintenance train which is provided with an acetylene light. In many instances this inspection is made with an electric locomotive handling the train. A steam locomotive is used, however, at such times as repairs are required, the power then being removed from the line upon which work is being done. During the winter months a considerable amount of ice collects on this construction at points where the water seeps through the tunnel roof. This ice is removed by means of long poles fitted with iron tips. The removal is ordinarily made without taking the power from the line. Doors are provided at the western portal, which are used during the winter to provide against the admittance of cool air, which would greatly increase the troubles resulting from the formation of ice.

Following the inception of a very extensive water power development on the Deerfield River, arrangements were made to supplement the power supply at Zylonite from this source. The hydro-electric station which is nearest to the tunnel comprises in its equipment two units which are designed to furnish alternating current of two frequencies, 25-cycle for railway work and 60-cycle for commercial service. Each one of these units consists of two 3 000 kilowatt three-phase generators and a water wheel, the rotors of the generators being carried on the same shaft. At present water power is not available at this station and the generating units are operated as frequency-changing sets receiving 60 cycle current at 2 300 volts and delivering 25 cycle current at 11 000 volts. The transmission net work which supplies this station is oper-

ated at 69 000 volts. It is expected that the water wheels will be in service in 1915 and the station will then be able to furnish about 12 000 kilowatts continuously. A transmission line two and one-half miles long, over which single-phase current is furnished for train propulsion, has recently been built from East Portal to this station. A second line used for the transmission of three-phase current at 33 000 volts connects this station with the Zylonite plant. The energy supplied over this line is ordinarily used by the Berkshire Street Railway Company for its trolley lines, but it is available under certain conditions for train operation in the electric zone. An agreement is effective between the Connecticut River Transmission Company and the Berkshire Street Railway Company which provides for the sale of power to the Connecticut River Transmission Company during periods of extremely low water.

The main line tracks in the electric zone are equipped with automatic electric signals, operated by 60 cycle current supplied at 2 200 volts by the local company. Two of these signals, equipped with indicating lights in place of semaphore blades, have been installed on each track in the tunnel in such a a way as to practically divide it into three blocks. These particular signals are made positive in effect through the use of a special telephone circuit connecting each signal location with the signal towers at the portals. In case the signal is red the engineman must obtain a clearance by telephone from the operator before proceeding. This telephone circuit and the power and control circuits for the operation of the signals are carried in lead covered cables which are suspended from the side wall of the tunnel. A second telephone circuit is carried through the tunnel with stations 3 000 feet apart. This circuit is ordinarily used by the trackmen and miners, but is available at all times for general use.

In the foregoing there has been no attempt at a description of the electrification as this has already been adequately described.* It has been the purpose to touch upon a few of the operating features which appear to be peculiar to tunnel operation, and particularly to the operation of Hoosac Tunnel. The increase in the capacity of the tunnel with its consequent facility of train movement, the added safety for operating men, and the increased comfort for the traveling public, which were effected by the electrification, were all anticipated, but many of the less important features are novel. The decreased amount of smoke and exhaust steam which resulted in a drier, purer air having a smaller acid content, brought with it lengthened life of the rail, spikes and tie plates, and increased opportunity for work which resulted in marked decrease in maintenance cost. But this drier air introduced a serious problem in motor maintenance by releasing immense quantities of soot which had accumulated in some places to the depth of a foot on the walls and in the galleries during the thirty years of steam operation—soot, harmless in its moist condition but a serious menace when dry. Even though the steam locomotives are hauled through the tunnel, they still give out enough vapor of an acid nature to cover the wires with a corroding moisture destructive in itself but more troublesome yet by showering the roofs and insulators of the locomotives with a corroding and conducting compound which has made roof preservation difficult and the ordinary pantagraph trolley insulation inadequate.

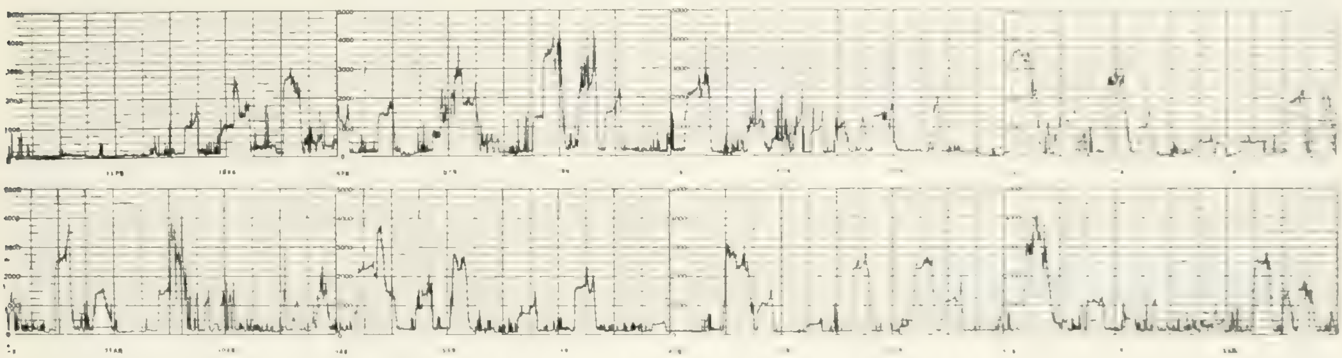

FIG. 4—GRAPHIC WATT-HOUR METER RECORD OF THE TUNNEL LOAD

These interesting problems in maintenance, as they arise, must be met. None of them are of an alarming character, and when weighed against the benefits that have accrued from the electrification, while not insignificant, are relatively small. The results of three years of operation have justified the wisdom of electrifying the tunnel, and a record of no electric failures on the distribution system within its portals during that period, speaks well for the designs upon which the construction was installed.

*See article by Mr. H. K. Hardcastle, in the JOURNAL for October, 1911, p. 830.

The Solution of a City's Transit Problem*

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THE expansion in area of the great cities in recent years which in large part has been made possible by and has resulted from improved transit facilities has forced upon them the necessity of securing still further improvement of such facilities to permit the expansion to continue. Where existing facilities are unduly congested, relief must be secured. The channels through which the traffic of great cities flows or should flow, must afford prompt, efficient service to the traveling public with a resultant convenience and saving in time and in money. Every important section of a city should be made readily accessible from every other important section of such city, in point of time, comfort and cost. Undue congestion of population, or the only other alternative, stagnation, must be avoided by making outlying undeveloped areas readily accessible for development. Therefore, it has become necessary to devise methods of determining city transit requirements, and to provide therefor.

A. MERRITT TAYLOR

The definite problem in each case is to determine:—

1—The type, location and extent of the improvement in transit facilities.
2—The best method of securing the necessary money and the best policy as to ownership and operation.
3—The probable volume of traffic and the degree in which direct revenue and contingent benefits will pay the fixed charges on the investment.

The notes herewith presented relate only to type, location and extent of improvements warranted and the probable volume of traffic and operating results, but do not deal with the question of financing these improvements or policy as to ownership and operation.

REQUIRED DATA

The first requisite in the solution of this problem is an accurate exposition of the existing situation, comprising the location of the population in workable detail and the direction, length, time and frequency, on the average, of the journeys made by each group or section of the population. A satisfactory method of estimating the number of present passengers who would use a high speed line in preference to the present lines gives, then, a sound basis for determining the necessity for and the prospective volume of traffic on a high speed system.

Future increase in the habit of riding and in the number of people tributary to any lines proposed must be matters of estimate. The business foundation of the project, however, will rest on the actual traffic existing, and it is therefore absolutely necessary to ascertain the characteristics and volume of this traffic with the greatest possible and practical degree of accuracy. The estimates of future increases must be predicated conservatively upon past experience in other cities and in the city in question wherever it can be found.

The prominent features of the particular problem in Philadelphia are the wide extent and comparatively low density of population, the scarcity of wide and diagonal streets and the localization of the interests of a large part of the population in the neighborhood of large industrial plants and centers. A part of the methods adopted in Philadelphia to reach a solution of the problem are here presented in detail.

STUDY OF THE POPULATION

Location of 1910 Population—On a street map of Philadelphia, of which Fig. 1 shows one square mile, the 1910 U. S. Census enumeration districts, of which there are 1 293, were outlined. Within the boundaries of each of such districts were entered as shown in Fig. 2:—

1—The identification number thereof (in the upper right hand corner of each district).
2—The population thereof (upper figure in each district).
3—The density of the population thereof per acre which was determined by dividing the population by the area in acres (lower figure in each district).

The area in acres of each enumeration district was integrated by means of a planimeter.

Population Estimated for 1912—The population as of 1912 was estimated by four methods and composite or average estimates made therefrom for each ward.

1—One-fifth of the actual increase in population of each ward as shown by the United States Census for 1910 over 1900 was added to the 1910 population of such ward in order to arrive at the estimated population thereof for 1912.

Example—(Ward 23)
1910 Population, 32 133
1900 " 26 109

6 024 ÷ 5 = 1 204 (Increase 1912 over 1910)
\+ 32 133 (1910 population)
33 337 = Estimated population, 1912

2—From the records of the City Board of Compulsory Education was obtained the number of school children, ages 6 to 15 inclusive, in each ward. For 1910, dividing the population of the ward by the number of school children therein gave the ratio of school

*The statements and maps referred to other than those illustrated herein are contained in Report of Transit Commissioner, City of Philadelphia, July, 1913, to which this article is supplementary.

children to population, and for 1912 the ratio was increased one percent in accord with the tendency of previous years.

Example—(Ward 23)
1910 Population, 32 133 } 6.00
1910 School children, 5 356
This ratio × 1.01 = 6.06 = 1912 estimated ratio of school children to population.

FIG. 1—ILLUSTRATION OF BASE STREET PLAN USED
Traffic section No. 26, scale—3 inches = 1 mile.

The number of 1912 school children was multiplied by the 1912 estimated ratio to arrive at the estimated population of each ward for 1912.

Example—(Ward 23)
Number of 1912 school children, 5 586 × 6.06 = 33 851 = estimated population.

3—From the records of the County Commissioners was obtained the number of assessed voters in each ward for December, 1909, and December, 1911. The 1910 population of each ward was divided by the number of December, 1909, assessed voters for the 1910 ratio, which was increased two percent in accord with the tendency of previous years for the 1912 estimated ratio, and the number of December, 1911, assessed voters was multiplied by this ratio for the 1912 estimated population.

Example—(Ward 23)
Population, 1910, 32 133 } 4.26
Assessed voters in December, 1909, 7 537
Ratio 4.26 × 1.02 = 4.34 = estimated ratio. Assessed voters, December, 1911 = 7 785 × 4.34 = 33 787 = estimated population 1912, based upon assessed voters.

4—The number of dwellings erected during the years 1900 to 1910 was ascertained for the entire city by natural groups of wards from the records of the City Bureau of Building Inspection. The increase in population for the same period was determined for these groups from the United States Census. The latter figure was divided by the former, giving the increase in population per dwelling built during this period. The number of dwellings built during the decade was considered as substantially the same as the number newly occupied during this time. Therefore the result may be regarded as increase in population per dwelling newly occupied without deduction for dwellings vacated.

The number of dwellings newly occupied in the year 1911 and the year 1912 was obtained by separate wards from the City Water Bureau. The number of dwellings newly occupied was then multiplied by the increase in population per newly occupied dwelling which was derived as described above. This product is, then, the estimated increase in population for the year. The increase for 1911 was then added to the population for 1910, given by the U. S. Census, to procure the total population for 1911, and the 1912 population obtained by adding its increase to the 1911 figure, as follows:—

Frankford and Bridesburg Group	Dwellings Built	Increase in Population
	1900 to 1910	1900 to 1910
Ward 23	1 362	6 624
Ward 35	947	1 870
Ward 41	1 034	4 [illegible]
Total for group	3 343	12 200

$\frac{12\,200}{3\,343}$ = 3.64, increase in population per new dwelling.

339 = new dwellings occupied 1911 (from city records)
339 × 3.64 = 1 233 = increase in population 1910 to 1911
Adding 32 133 (population, 1910, from U. S. census) the result is 33 366, the estimated population in 1911 for Ward 23
390 = new dwellings occupied 1912 (from city records)
390 × 3.64 = 1 420 increase in population 1911 to 1912
Add 33 366 population, 1911 (estimated above)

34 786 estimated population, 1912, for Ward 23

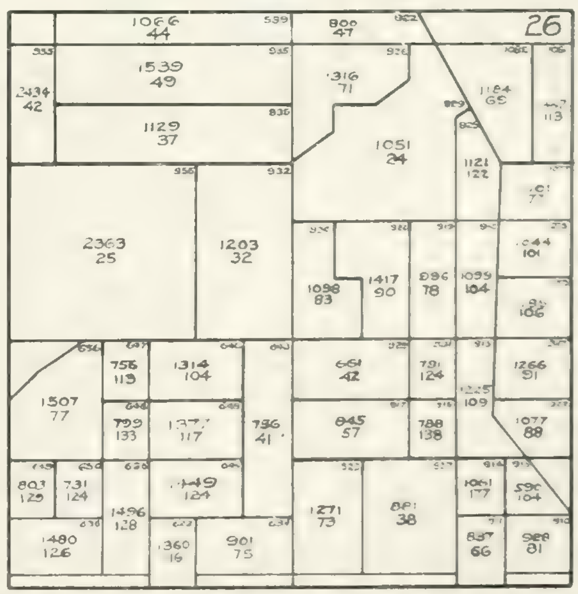


FIG. 2—ILLUSTRATION OF UNITED STATES CENSUS DISTRICTS
Traffic section No. 26, scale—3 inches = 1 mile. District number in upper right hand corner, 1910 population upper number, 1910 density of population per acre lower number

For the purposes of the Census, a dwelling house was defined in the instructions to enumerators as "a place in which one or more persons regularly sleep." It is not necessarily a house in the usual sense of the

word—a boat, a tent, a freight car or a room in a warehouse, though occupied by only one person, was returned as a dwelling; while, on the other hand, an entire apartment house, though containing many families, constituted only one dwelling.

FIG. 3 REPRESENTATION OF DISTRIBUTION OF POPULATION

Traffic section No. 26, scale—3 inches = 1 mile; black dot = 100 population, 1910 census; black dot surrounded by circle = 100 increase in population—1910 to 1912; black dot and line = 100 decrease in population—1910 to 1912.

A Composite Estimate, or average of the population, obtained by the above methods, was applied in correcting the 1910 population up to 1912 as follows:—

1—1912 according to rate of increase, 1900 to 1910..	33 337
2—1912 according to population of school age.......	33 851
3—1912 according to assessed voters................	33 787
4—1912 according to dwellings newly occupied......	34 780

As in this case the first three estimates agreed closely, the fourth was neglected and the average of the others 33 600, was estimated to be the population.

Spot Map—Over the foregoing street map (original scale 1 000 ft. to the inch) was placed a tracing through which the information contained thereon could be plainly seen. A city atlas corrected to date was used to determine the location of all residences in each enumeration district, and one spot was charted on the tracing representing each 100 population on the point which was the center of gravity of each group of nineteen dwellings. A solid black spot was used to indicate the location in 1910, and a small spot enclosed in a circle was used to indicate the location of the population increase between 1910 and 1912. A solid crossed spot was used to indicate the location of the population decrease between 1910 and 1912. This spot map is illustrated by the square mile section shown in Fig. 3.

Passenger Railway Map—Over the foregoing street map was placed another tracing and upon it all existing street railway, rapid transit and steam railroad lines engaged in the carrying of passengers were charted. An example of this is shown in Fig. 4 for the same square mile section.

Combination Base Map—By superimposing the spot map tracing upon the railway map tracing and by printing them in combination, a combination base map was derived showing the location of the 1912 population with relation to existing street railway, rapid transit and steam railroad lines engaged in carrying passengers.

TRAFFIC SURVEY

The solution of the transit problem is largely dependent upon accurate knowledge of the present and prospective flow of traffic into and between all sections of the city and the deficiency in the existing facilities. The deficiency may be due to inadequate capacity, inadequate speed, or both, or to excessive cost.

The present flow of traffic between all sections of the city was determined by a traffic survey made by the following novel and practical method.

Preparation for Survey—A program was prepared from schedules in effect on the Philadelphia Rapid Transit Company Lines. This program provided for counting the passengers on about one car in every five (eighteen hour) cars operated and averaged about four lines per day. Two men were placed on each car, the first man presenting an identification slip to each passenger and the second collecting the slip and inquiring the passenger's destination. The survey extended over a period of five weeks, from October 14, 1912, to November 18, 1912, which period was selected as representing most nearly normal traffic conditions in Philadelphia. No count was made on

FIG. 4 ILLUSTRATION OF MAP OF PRESENT FACILITIES

Traffic section No. 26; scale—3 inches = 1 mile.

holidays, Saturdays or Sundays. At the conclusion of the program the count was repeated on several lines in order to make sure that the method produced consistent and representative results. These recounts were found to agree satisfactorily with the originals. The results obtained from the count were very satisfac-

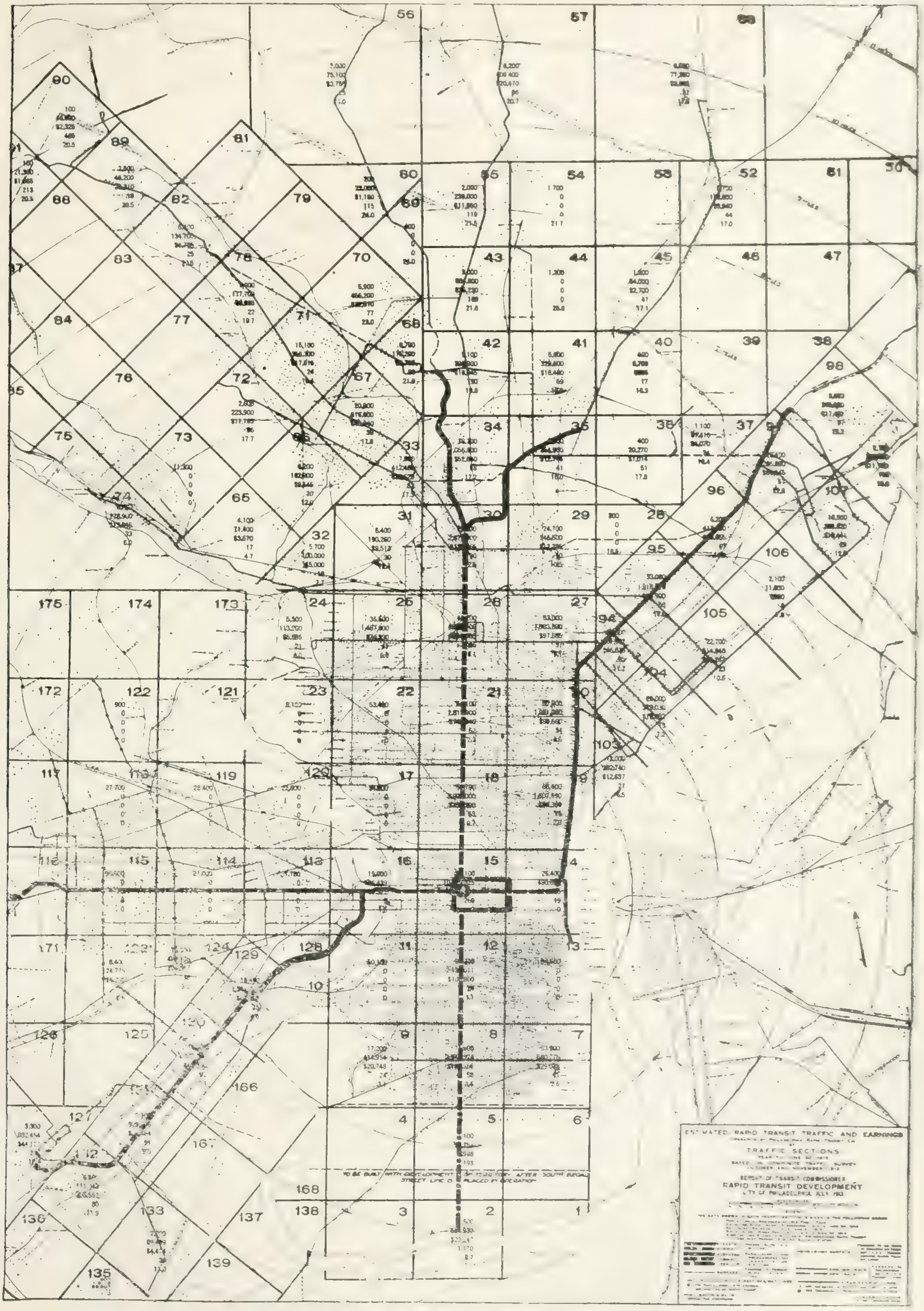


FIG. 5—ESTIMATED RAPID TRANSIT TRAFFIC AND EARNINGS
Showing location of traffic sections.

tory. These results in part were due to the following procedure:—Selection of the men engaged on the count from the ranks of the Philadelphia Rapid Transit Company's experienced conductors who worked under the direction and supervision of the Transit Commissioner's organization; the use of the most experienced conductors through the entire count as collectors of the traffic slips and of conductors employed on, and therefore, familiar with, the route of line being counted, as distributors; careful and minute verbal instructions were given these men regarding their duties and they were provided with distinctive cap and breast badges worn over ribbons displaying the city colors; wide publicity by advertising and explaining in the newspapers the purpose and method of the count was given.

Advertising—The traveling public was appealed to by placing display notices on the windows of *all* cars operated on each line during the entire day previous to the day of the scheduled count on that line. On the day of the count similar notices were shown on the windows of those cars only on which the count was actually being taken.

Chester Ave. LINE
City of Philadelphia
TRANSIT COMMISSIONER'S OFFICE
PASSENGER COUNT RECORD
ON AT STREET CORNER No 20
SECTION No 129
East BOUND
COLLECTED FROM PASSENGER — C E T ~~D~~
ISSUED TO PASSENGER — — — — E T
LEAVING TIME
5.10 P.M.
DESTINATION 40th and Market ST. ~~AVE.~~ 33
DESTINATION SECTION NO 113
STOP No.
BY EXCHANGE OR TRANSFER TO LINE
No. 65599 PLEASE KEEP THIS SLIP UNTIL COLLECTED No. 65599

FIG. 6—TRAFFIC COUNT SLIP USED FOR PASSENGER COUNT RECORD

Traffic Sections—A tracing was then prepared, Fig. 5, showing traffic sections of an area one mile square as far as practicable, and centered with respect to Market Street, North and South Broad Street, Woodland Avenue, Kensington Avenue and Germantown Avenue, the three latter being diagonal thoroughfares. These squares were numbered, beginning at League Island and numbering to the North, Northwest, Northeast, then West Philadelphia. By superimposing the traffic section tracing over the spot map it was possible to determine and tabulate the population of each traffic section by counting the spots representing population of 100 each. This map is illustrated by Fig. 5.

Stop Numbers—The street corners or points at which cars stop for passengers were identified by numbering the stops on each car line, beginning at the stand or starting point and numbering consecutively for the round trip each street corner at which the cars stop to receive or discharge passengers. The stop number for each line applied to that particular line only. For each car line, cards were printed by the Philadelphia Rapid Transit Company, one side of the card showing the street intersections and corresponding stop numbers for the "Out Bound" trip from the stand, or first half of the round trip, and the reverse side of the card showing the same information for the last half or return trip, or the "In Bound" trip. Large cards giving the same information were conveniently placed at each end of the street cars for use of the distributor and collector in marking the passenger count slips. They were also furnished with small cards, of size convenient for carrying in the hand, which showed the same information. This information for all lines was also printed in a paged and indexed pocket size book.

Count Slips—The distributor was provided with printed slips or tickets, somewhat larger than street car transfers, as represented in Fig. 6. These slips were in pads, 100 to the pad, and were numbered serially. They were in four colors, one color being used for trips in the general direction of each point of the compass.

Procedure on Cars—The distributor took a position near the entrance end of the car, where he could plainly see the class of fare each boarding passenger paid the car conductor. As each person boarded the car the distributor noted the stop number, as shown by the stop card, in the blank space on the count slip following the wording, *On at Street Corner No.* ——. As the fare was paid, the distributor made a pencil mark through the letters following *Collected from Passenger*; through *C* if a coin or ticket representing a cash fare, through *E* if an exchange ticket, through *T* if a transfer ticket, and through *D* if a pass, either complimentary or employe. He also made a pencil mark through the letters following *Issued to Passenger;* through *E* if an exchange ticket was issued to the passenger, indicating that an eight cent fare had been paid, and through *T* if a transfer ticket. This slip was then handed to the passenger with a request that he hold it until collected. In collecting the slips, the collector noticed if the *E* or *T* on the line reading *Issued to Passenger* was marked, and, if so, learned the street or car line to which the passenger intended to change to reach final destination. This street or car line name was entered in the blank space on the line reading *By Exchange or Transfer to* ——— *Line.* In either case (whether the *E* or *T* on the line with and following the words *Issued to Passenger* was marked), the collector ascertained the final destination street or avenue name and noted it on line reading *Destination* ——— *St.—Ave.* Different colored slips were used for each direction and at the end of each half trip the collector enclosed all slips collected for that particular half trip in an envelope giving the following information:—Number of that particular envelope corresponding to the number of half trips counted; name of collector; date; name and block number (run or train) of line being counted; direction; time of beginning of half trip; number of slips enclosed; delays; unusual traffic movements; other notes.

Procedure in Office—All envelopes containing slips were turned into the office of the Transit Commissioner after midnight and before office hours the following day. There a force of men especially selected from among the experienced conductors, with the aid of a set of stop lists on which the stops were grouped or blocked off by traffic sections, noted and entered the traffic section number in the blank space on the count slip following *Section No.* ———. Next, if the final destination street or avenue was on the car line of origin, i. e., if the passenger was able to reach his street of residence or occupation without an exchange or transfer to another car line, reference was made to the same stop list and the stop number shown for that street or avenue entered in the blocked space

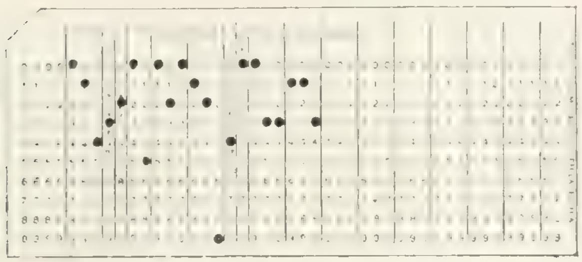


FIG. 7—HOLLERITH CARD CODE

following *Destination street or avenue.* Underneath in the blocked space following *Destination Section No.* ———, was entered the number of the traffic section in which that street was enclosed. When count slips indicated that an exchange or transfer had been issued to the passenger, i. e., the name of the car line written in the blank space *By exchange or transfer to* ——— *line,* the route number of that particular car line was entered in the bottom blocked space at the lower right corner; then the same procedure as before gave the information for the two blocked spaces next above except that it was necessary to refer to the stop card for the line on which the transfer or exchange was used.

Statistical Machine Work—The count slips were then sent to the "Statistical Service Company" in the original envelope. All envelopes showing a time between 6.00 and 8.59 A.M., inclusive, were next separated and classed as the morning rush hour or peak loads. Those showing a time between 4:00 and 6:59 P. M. inclusive were kept in a separate bundle and classed as the evening rush hour or peak loads. The remaining envelopes made up the non-rush hour travel. This separation was necessary in order to get the true ratios under the conditions at different hours of the day.

The work of the "Statistical Service Company" using 24 columns of the Hollerith card code consisted first of punching a card from the information contained on each count slip as follows:—

Example—A count slip enclosed in an envelope for Chester Avenue Line—Route No. 14 would read as follows:—

[illegible]

[illegible]

[illegible]

[illegible]

Collected from Passenger [illegible]

Destination [illegible] 33

Destination Section [illegible]

The card would be punched as follows, as shown in Fig. 7:—

[illegible]
Line No. .... [illegible]
1 punched in 2nd column
4 punched in 3rd column
Direction [illegible]
A. M. or P. M. [illegible]
Time [illegible]
Street Corner Origin...............0 punched in 1st column
2 punched in 2nd column
0 punched in 3rd column
Section Origin ....1 punched in 1st column
2 punched in 2nd column
[illegible]
Class Fare .... 4 [illegible]
Exchange or Transfer Issued........0 punched
Street Corner Destination..........0 punched in 1st column
3 punched in 2nd column
[illegible]
Section Destination [illegible]
1 punched in 2nd column
3 punched in 3rd column

With electrical sorting and recording machines, the cards for each line divided under the three subheadings were sorted and recorded for each traffic section of origin, also for each traffic section destination as shown by "Statement No. 15,*" which represents the actual number of passengers paying cash fares (either 5 or 8 cents) on cars counted, and this statement is a copy of the information as received from the "Statistical Service Company."

Compilation of Records of Total Traffic—From copies of all schedules in operation received from the Philadelphia Rapid Transit Company, statements* (See Statements Nos. 12 and 13) were prepared, showing a tabulation of passengers according to the leaving time (arranged consecutively) of each half trip. From the conductors' way bills (day cards or trip sheets) loaned by the Philadelphia Rapid Transit Company the 5 cent cash fare—5 cent ticket fare (representing cash) and 8 cent cash fare columns opposite each leaving time shown, were totaled and entered opposite the corresponding leaving time on the statements. Entries were separated in two columns—one for the cars counted, the others for cars not counted. Statement No. 14 was next prepared by totaling the passengers for both directions from 6.00 to 8.59 A. M. inclusive and posting as the "Morning Rush Hour" passengers, from 4.00 to 6.59 P. M.

*These "statements" are given simply as of reference value, being of too great length to be included in this article. They together with the maps referred to may be examined if desired as stated at the beginning of this article.

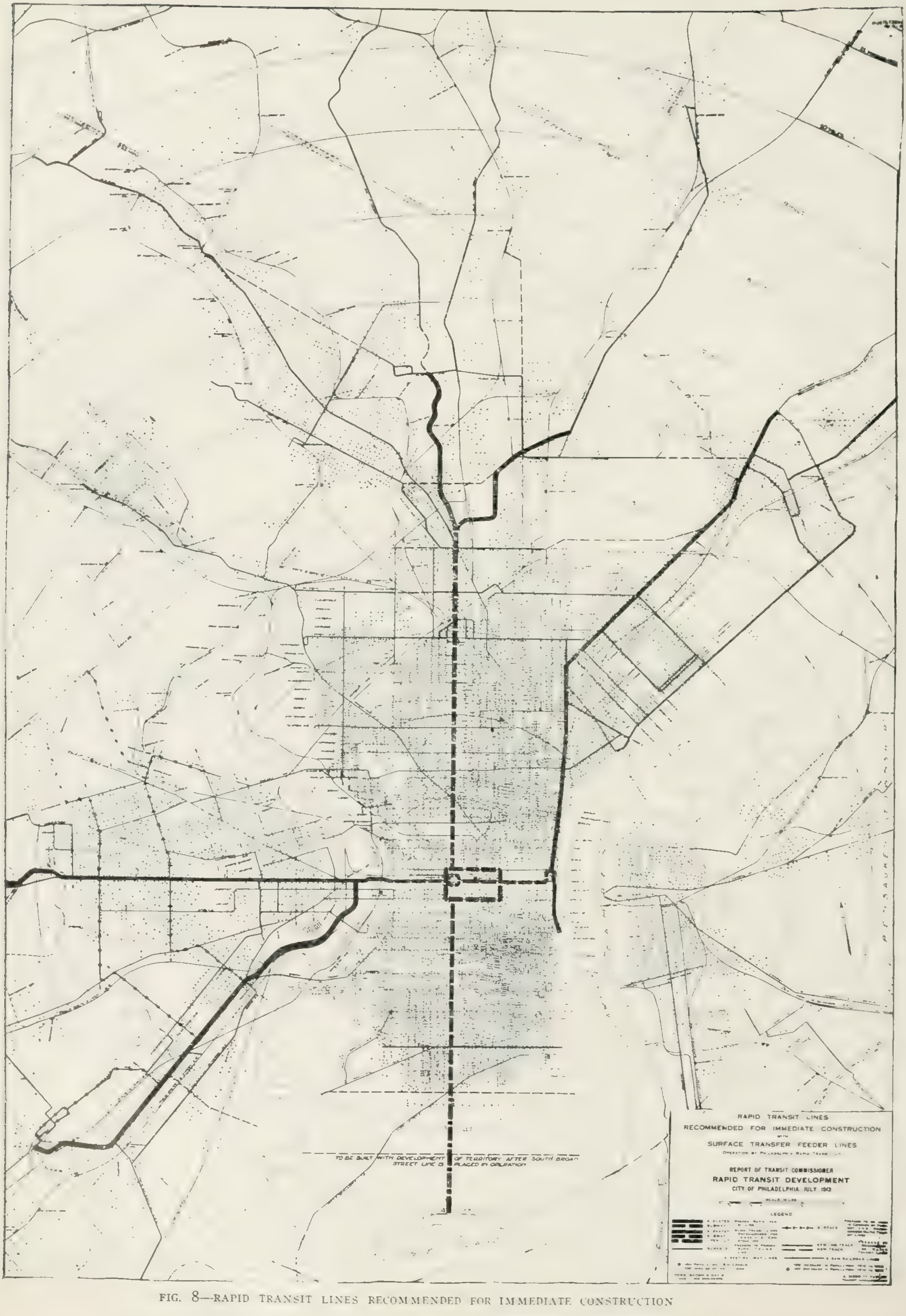


FIG. 8—RAPID TRANSIT LINES RECOMMENDED FOR IMMEDIATE CONSTRUCTION

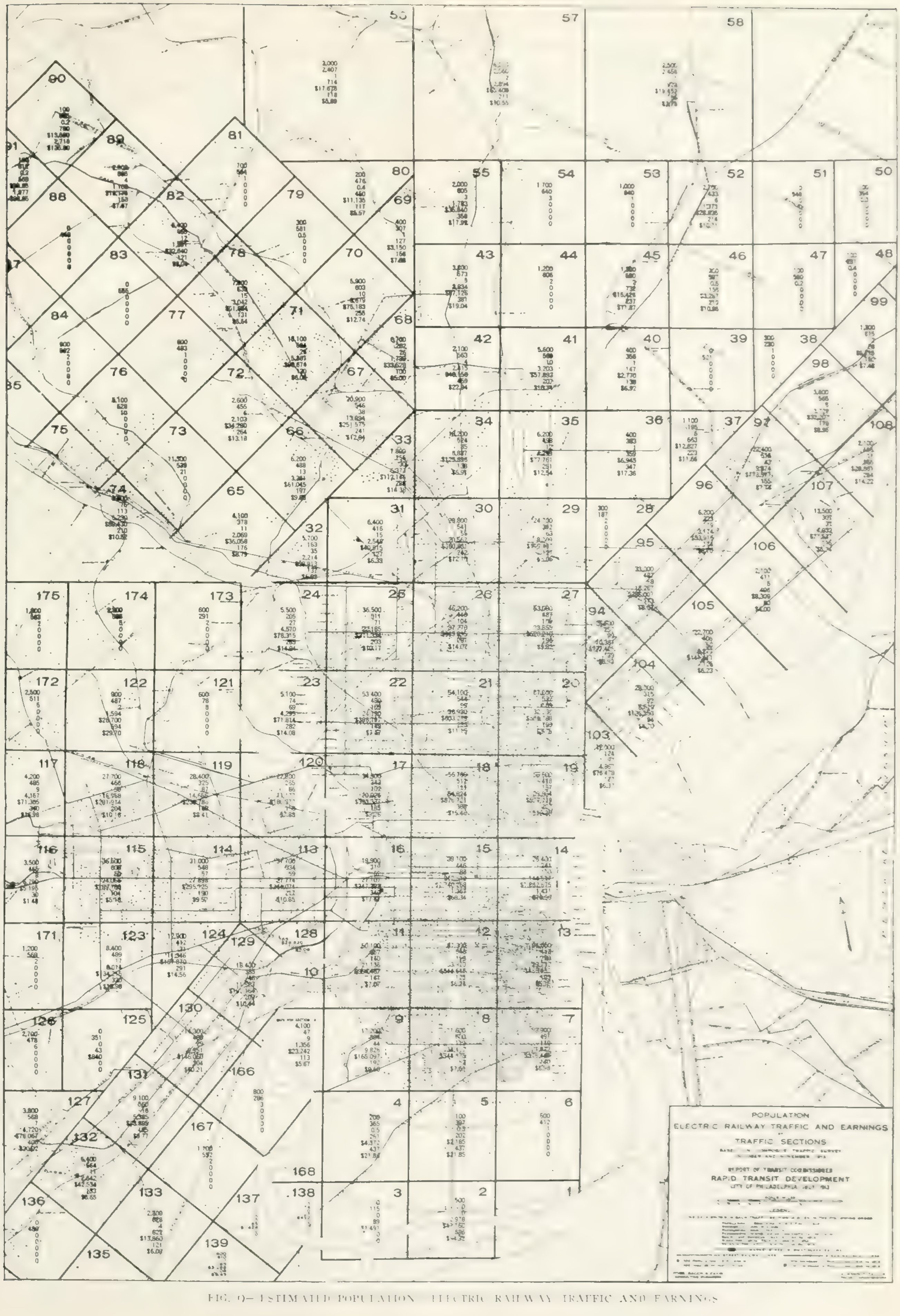


FIG. 9—ESTIMATED POPULATION, ELECTRIC RAILWAY TRAFFIC AND EARNINGS

inclusive as the "Afternoon Rush Hour," the balance as the "Remainder of Day." Statement No. 16 represents the figures on Statement No. 15 multiplied by the ratio of passengers counted to the total passengers carried on the day counted. The ratios were determined as follows:—

Morning Rush Hour.

Total passengers	(Statement 14)	3688	5.521	6 to 9 A.M. Ratio.
Counted passengers	(Statement 15)	668		

Afternoon Rush Hour.

Total passengers	(Statement 14)	4824	5.186	4 to 7 P.M. Ratio.
Counted passengers	(Statement 15)	930		

Remainder of Day.

Total passengers	(Statement 14)	7012	5.682	Rmdr. of Day Ratio.
Counted passengers	(Statement 15)	1234		

The result obtained on "Statement No. 16" was summarized by adding the passengers shown for each period for 6 to 9 A. M., 4 to 7 P. M., and remainder of day, and showing these totals on "Statement No. 17."

"Statement No. 18" represents the figures shown in "Statement No. 17" multiplied by the ratio of passengers carried on the day counted to total passengers carried for the year to June 30, 1913.

For the Cumberland Street Line the yearly ratio was determined as follows:—

$$\frac{\text{Total yearly passengers carried} \ldots\ldots 4\,740\,139}{\text{Total passengers carried day of count} \quad 15\,554} = 305 \text{ yearly ratio}$$

The passengers shown to sections *reached directly* are passengers destined to sections through which the line runs. The passengers shown to sections *reached by surface transfer* are passengers changing to a second car either with an eight cent exchange ticket or a free transfer. The result for each line as shown by "Statements Nos. 17 and 18" was posted on a traffic section map (one map for each of the 113 sections) similar to Map No. 31 of Volume II, Transit Commissioner's 1913 Report, which represents traffic section No. 26. The figures posted on this map are the total cash passengers boarding cars of the twenty-three lines that operate through Section No. 26 and finishing their journey in the sections where posted. With these maps it is possible to determine the volume and direction of all present street car traffic movements to, from and between divisions, wards or localities of the city as small as a mile square, and while not posted on maps, the information is available by street corners and intersections. This information in conjunction with route schedules develops the time required and volume of traffic affected between all sections.

Summaries of Traffic by Districts—The traffic section maps were then grouped by districts as shown on Maps 37 to 41 inclusive. As an illustration, Map 37, representing the business or central delivery district is the total cash passenger movement (357 359) for the day of the traffic count originating in Sections 14 and 15, and distributed to the various districts as indicated by proportional colored ribbons. The sections are outlined in black, and the colored ribbon labeled "South Philadelphia between Eighth and Twentieth Steets" represents 30 213 daily cash passengers from Sections 14 and 15 combined to Sections 2, 5, 8 and 12 combined. Also that reading "North Philadelphia east of Eighth Street," represents 24 968 daily cash passengers from Sections 14 and 15 combined to Sections 19, 20 and 27 combined. Of the passengers originating in the "Central Delivery District," 68 029 are destined to points within that district.

Suburban, Electric and Steam Railroad Traffic—Traffic on suburban electric railway lines in the outskirts of the city was similarly analyzed and charted. Similar statistics with relation to traffic on steam railroads and ferry lines entering the city was furnished to the department by the operating companies.

Conclusions from Survey—With the information thus derived as to the volume of traffic flowing between all sections, and with the capacity of existing facilities to move the same ascertained, all present deficiencies in capacity were readily determined. It was also ascertained from the result of the traffic survey, coupled with schedules of routes available, what volume of traffic was inconvenienced by excessive time of travel and required relief. This information, taken in conjunction with the probable increase of population of the city, the location thereof, and traffic to be derived therefrom, designated the general channels which now require and will require the relief afforded by a high speed system.

Routes Selected—These main or general channels as shown by Fig. 8 are as follows:—

1—A north and south line for almost the extent of the city limits and located principally in Broad Street, which is the only wide thoroughfare running north and south, and which is located in approximately the center of the main body of the city, lying between the Delaware and Schuylkill Rivers. (As the principal down-town business district, or, as hereinafter designated the "Central Delivery District," lies at right angles and principally to the east of Broad Street, it was found necessary to make a detour in the Broad Street Line. This loop or detour is about 0.6 of a mile east and west by about 0.3 of a mile north and south, and is so designed that the trains may be operated through from north to south either directly in Broad Street or by way of the detour, and so that trains from either the north or south can be operated all the way around and returned directly.)

2—A line known as the Frankford Line, constituting an extension of the present Market Street Line into the populous northeastern district of the city.

3—The line branching from the present Market Street Line west of the Schuylkill River and extending southwestwardly to serve the large undeveloped areas and to tie in the important districts along and near the Delaware River below the city, and a line extending from the Central Delivery District northwestwardly for the later construction of which provision is being made. (The calculations herein explained do not take account of this last line.)

Map Summary of Traffic Survey by Traffic Sections—The traffic figures obtained from the traffic survey after classification and compilation were displayed in summarized form by traffic sections on Map No.

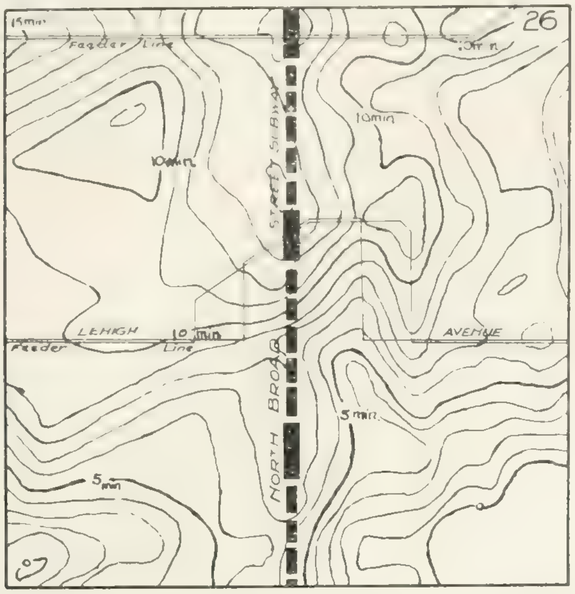


FIG. 10 ILLUSTRATION OF TIME SAVING CONTOURS AND PROPOSED FACILITIES

Traffic section No. 26, scale—3 inches = 1 mile.

29 of the Transit Commissioner' Report, of which Fig. 9 is a reduced copy.

Using traffic section No. 26 as an example, the information on this map is explained as follows:—

A— 46 200—Population at beginning of 1913 fiscal year.
B— 446—Residential area in acres.
C— 104—Population density per acre.
D— 37 270—Passengers originating on composite day of count.
E—$649 895—Equivalent revenue, year to June 30, 1913.
F— 281—Rides per capita, year to June 30, 1913.
G— $14.07—Revenue per capita, year to June 30, 1913.

A—Population obtained as hereinbefore described.
B—Details of the calculation of net residential area as follows:—
Gross area of Traffic Section....................640 acres
Area unavailable for dwelling purposes:—

Cemeteries	215 000	sq. ft.
Parks	200 000	" "
Railroad property	3 770 000	" "
Institutions	65 000	" "
Churches	155 000	" "
Factories	3 617 000	" "
Government property	123 000	" "
Miscellaneous	308 000	" "
	8 453 000	" "

Divided by sq. ft. per acre—43 560 = 194 acres.

Then 640—194 = 446, residential area in acres.

C—Population of Traffic Section No. 26 for 1913 = 46 200 (obtained by counting spots on Population map).

Then 46 200 ÷ 446 = 104 = Density of Population per acre.

D—This value was obtained by summarizing the daily grand totals (from Section No. 26) for the 23 lines operating through Section No. 26, as illustrated on statement No. 17 for the Cumberland Street Line, Route No. 19, grand total 1 411.

E—Obtained by multiplying 12 997 901 (the total yearly surface passengers originating in Section No. 26, as shown in this article under heading "Summary of all Traffic Tributary") by 5 cents.

F—Obtained by dividing 12 997 901 (the total yearly surface passengers) by the 1st item, (46 200, the population at beginning of 1913 fiscal year).

G—Obtained by dividing the 5th item ($649 895, Equivalent revenue year to June 30, 1913) by the 1st item, (46 200, the population at beginning of 1913 fiscal year).

TIME OF TRANSIT

Time Zones—As shown from the traffic survey, the great volume of traffic flowing into the central delivery district in the city, bounded by Arch Street on the north, Walnut Street on the south, the Delaware River on the east and the Schuylkill River on the west, constitutes the most important movement and has the greatest need of relief; therefore a time zone map was prepared to illustrate the time required in traveling between that district and every other district in the city.

Time Saving Maps—The time saving map, one square mile of which is shown by Fig. 10, shows graphically by contours the time saving that will be effected by the proposed rapid transit lines as compared with the present facilities. The time saving contours are arrived at as follows:—

1— [illegible]
2— [illegible]
3— [illegible] tem map over the present system map.

The average time saving of each traffic section is calculated from this time saving contour map.

1—Time Zones—Present System—The time zone map of the present system, (square mile section illustrated by Fig. 11) shows graphically the time of transit by the shortest route from any point on Market Street between Eighth and City Hall or on Broad Street between Arch and Walnut Streets. For example, the time by a route running north on Eighth Street was measured from Eighth and Market Streets, while the time by a route running west on Walnut Street was measured from Broad and Walnut Streets.

In measuring the time of transit along all routes not reaching this central traffic zone directly, the use of an intervening route was necessary and allowance was made for transferring between cars. Also to obtain the running time accurately, schedules of the present surface routes were obtained from the Philadelphia Rapid Transit Company. These gave the time between points on the various lines. The scheduled running time of suburban lines was also obtained. These time points were laid out on the track map (Scale—3 inches = 1 mile) and the route between

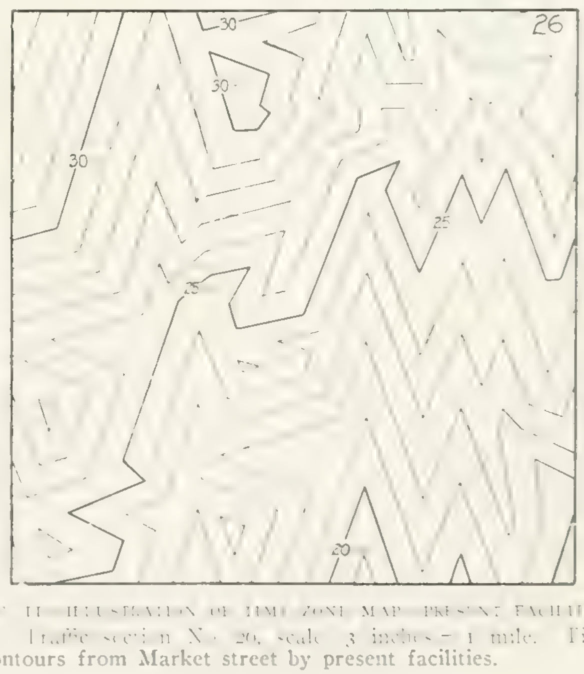


FIG. 11 ILLUSTRATION OF TIME ZONE MAP—PRESENT FACILITIES

Traffic section No. 26, scale—3 inches = 1 mile. Time contours from Market street by present facilities.

the time points divided at intervals of one minute. A paper scale was then made for each line by means of which the running time in minutes could be measured

along any section of the route. This shortest time from the central zone, at intervals of one minute, was then laid out on the track map making time allowance for changing cars.

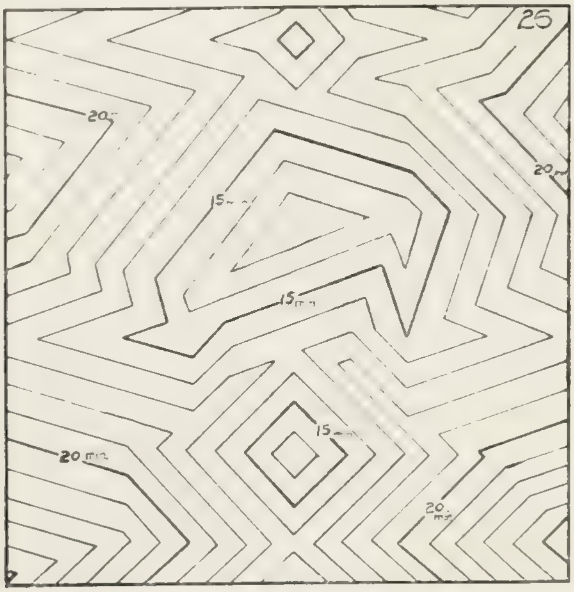


FIG. 12—ILLUSTRATION OF TIME ZONE MAP—RECOMMENDED FACILITIES

Traffic section No. 26, scale—3 inches = 1 mile. Time contours from Market street by recommended facilities.

The ride was limited to one fare within the city limits except in cases where suburban lines were used. In measuring running time the following differentials were allowed:—One minute for transfer from one car to another and one minute for walking up or down strairs at subway-elevated station with another minute for transfer to a surface transfer line, making three minutes differential for subway-elevated line in connection with surface transfer line. An average walking rate of three miles per hour was assumed and contours were drawn connecting all points reached in equal times either by direct riding or by a walk in connection with the ride. These contours were drawn at intervals of one minute.

These maps were checked by the large number of actual observations made by office employes during an extended period.

2—Time Zones Recommended Rapid Transit System—These zones (square mile section illustrated by Fig. 12,) show the time of transit to points reached directly or by surface transfer from the proposed Broad Street Subway and Frankford and Darby Elevated Lines. The running time for the proposed rapid transit lines was measured from the following points:—

Broad Street Lines	Market Street
Frankford Line	8th and Market Streets
Darby Line	13th and Market Streets

The locations of the stations and surface transfer lines were selected and the distance between stations determined. The running time between stations was estimated on the basis of a crest speed of 26 miles per hour; rate of acceleration of 1.25 m.p.h.; rate of retardation of 1.75 m.p.h.; and station stops of 20 seconds each. Express service between the more important stations was also provided for.

A differential of one minute was allowed for ascending and descending subway or elevated stairways with an additional minute for transfer to surface feeder line cars. A walking rate of three miles per hour was used. The present running times of the lines selected as surface feeders were used and where the construction of additional surface feeders was projected in thinly populated sections, a rate of 10 m.p.h. was used. Contours were then drawn at one minute intervals through points reached in equal time either by walking from stations or by the use of the selected surface lines.

3—Time Saving Contours—The time saving map is derived by comparing the present system time contours and the proposed rapid transit system time contours and shows graphically by contour lines at one minute intervals, the time saving that will be effected at every point by the proposed lines.

As illustrated by Fig. 13, the estimated time contours of the proposed rapid transit system, with selected transfer feeder lines drawn on transparent cloth, were superimposed on the map of the present system time contours, so that the value of the time contours or zone boundaries of each could be seen. By connecting the intersections made by the time contours on the present system map with those on the proposed system map, which differ by the same intervals, time saving contours were obtained. The points of zero time saving or equal time of transit were obtained in the same manner.

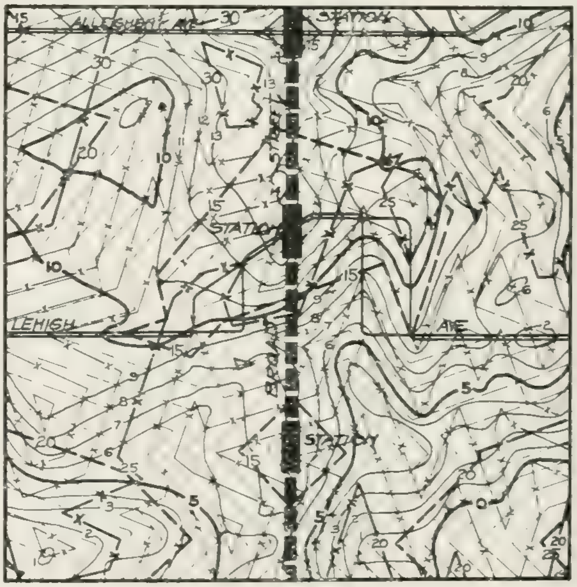


FIG. 13—ILLUSTRATION OF METHOD OF PLOTTING TIME SAVING CONTOURS

Traffic section No. 26, scale—3 inches = 1 mile. Dash and cross lines—present system time contours. Broken lines—proposed system time contours. Solid curved lines—time saving contours.

Example:—On the time saving map (Fig. 13), which refers to the base in the "Central Delivery District" it will be noticed that the zero time saving contour, or line of equal time of transit by present or

proposed systems, is drawn through the intersections of time contours of equal value—the intersection of the 20 minute time contour via proposed system with the 20 minute time contour via present system, etc. In the same manner, at the intersection of the 20 minute proposed contour with the 30 minute via present system, the ten minute time saving contour appears, and procedes through the intersection of 19 proposed with 29 present and so on. The intermediate time saving contours are arrived at in the same manner.

TABLE I—AVERAGE TIME SAVING SECTION 26

Time Saving in Minutes

At Internal Points.		At Border Points.	
0½	7½	[illegible]	13
3	11	[illegible]	[illegible]
[illegible]½	1[illegible]	1[illegible]	[illegible]
7	1[illegible]½	3	4
5½	11	6	6
4½	10½	3½	[illegible]½
4	7½	[illegible]½	6
[illegible]	11	10	5½
6	11½	9	4
7	13	11	8½
7	11	10½	9½
8½	10	12	10
7	7	13½	10
8	[illegible]½	1[illegible]½	12½
7	11		
9	13		
10	10½		
10	10½		
Total time saved. 302½ at 36 points		Total time saved..203 at 28 points	
Multiply by .... 4 at 4 points		Multiply by ..... 2 at 2 points	
1210	144	406	56

Similar time zone and time-saving maps were made using the following locations as bases or starting points:—

South Philadelphia ....Broad Street and Oregon Avenue
Darby ....9th and Main Streets
Germantown ....Germantown and Chelten Avenues
West Philadelphia..................52nd and Market Streets
North Philadelphia ....Broad and Cambria Streets
Frankford...............Frankford Avenue and Arrott Street

The neutral or influence line between the Frankford and North Broad Street lines is obtained by connecting the intersections of the rapid transit time-saving contours originating from the Frankford Line with those of equal time-saving by the North Broad Street line. This influence line shows the division of territory tributary to the respective lines with reference to the Central Delivery District.

Average Time Saving—It has been determined from the results of the traffic survey, that traffic originating in West Philadelphia divides as between surface and rapid transit in regular proportions according to time saving. Consequently, in estimating the division of traffic in a territory served by the proposed rapid transit lines, a time saving basis was used and the average time saving in each traffic section was determined.

These traffic sections, as before described, are generally one mile square, so located as to form zones along the present and proposed subway and elevated lines, approximately one-half mile on each side of each line. A few traffic sections are irregular in shape. In all, where traffic was material, there were 113 traffic sections served by the present electric railway lines.

The average time saving was calculated for each traffic section served by the proposed rapid transit lines, by the coördinate system, according to the following methods:—

The traffic section under consideration was plotted on the time saving contour map and sub-divided into small squares.

The value of each point of intersection of the coördinates was read from the nearest time saving contour. Each reading was multiplied by the number of squares having corners at the point read, as follows:—On internal points multiply reading by four and on border points multiply reading by two.

The total of all these values was divided by the total number of points, each taken as many times as the reading at that point was taken and the result thus obtained was the average time saving of the traffic section. A typical set of readings for such a case is shown in Table I. From the results therein given it is evident that the total equivalent number of readings are $144 + 56 = 200$ and the total equivalent number of minutes saved are $1\,210 + 406 = 1\,616$. Therefore, in this case the average time saved in the section is $1\,616 \div 200 = 8.08$ minutes.

ESTIMATED TRAFFIC OF RECOMMENDED RAPID TRANSIT SYSTEM

In order to determine the number of passengers that would use the proposed high-speed subway or elevated lines in preference to the present surface street car lines, a careful study was made of the division of traffic between these two classes of lines in West Philadelphia.

Division of Traffic in West Philadelphia—The division of traffic between the surface lines and the Market Street Subway-Elevated line was determined for each traffic section in West Philadelphia served by the Market Street subway-elevated line. This was accomplished by means of the traffic survey of all lines taken in October and November, 1912. A diagram showing the time saved in West Philadelphia by the Market Street subway-elevated line over the surface

TABLE II—RELATION BETWEEN TRAFFIC DIVERTED AND TIME SAVED BY HIGH SPEED LINE BETWEEN WEST PHILADELPHIA AND THE DELIVERY DISTRICT

Traffic Sections Served [illegible]	Percentage of Passengers using Market St. Subway-Elevated	Average Time Saving by Market St. Sub-Elevated [illegible]
No. 16	19.5	[illegible]
No. 113	38.4	[illegible]
No. 114	[illegible]	7.5 minutes
No. 115	[illegible]	10.9 minutes
No. 116	[illegible]	13.5 minutes
Traffic Sections Served by Surface [illegible]		
No. 1[illegible]1	[illegible]7	1.5 minutes
No. 128	15.6	2.0 minutes
No. 129	17.7	[illegible]
No. 130	19.1	2.4 minutes
No. 119	[illegible]	4.3 minutes
No. 124	46.8	4.3 minutes
No. 123	59.4	7.9 minutes
No. 118	65.8	9.1 minutes
No. 117	76.6	12.0 minutes

*Abnormal due to 69th street terminal.

and subway-surface lines was made; and the average time saving from Eleventh and Market Streets calculated for each traffic section. (Map No. 28, Vol. II—1913 Report.) In this manner fixed relations were developed between the time saving in minutes and the proportion of passengers using the high-speed line in preference to the surface lines. The result is shown in Table II.

Diagram of Division of Traffic—From the above data, curves *I* and *II* of Fig. 14 were developed for use in estimating the probable traffic diverted from the present system to the proposed subway and elevated lines. Curve *I* shows the proportion of passengers using the high-speed line from sections along the line to the "Central Delivery District."

Curve *II* shows the proportion for traffic sections reached by surface transfer lines in connection with the high-speed line. For traffic movements via the proposed rapid transit lines involving two transfers against a direct ride via surface or three transfers via proposed rapid transit lines against one at present via surface, curve *III* was estimated. While the division of local traffic in West Philadelphia varies, the averages for all such movements are found to follow the middle and lower curves. For short distances, however, where the time saving is small, the proportions of rapid transit traffic are higher than indicated by the curves. Thus of intra-section traffic in West Philadelphia, the Market Street Subway-Elevated Line is found to get an average of ten percent, and of traffic between adjoining sections about 18 percent.

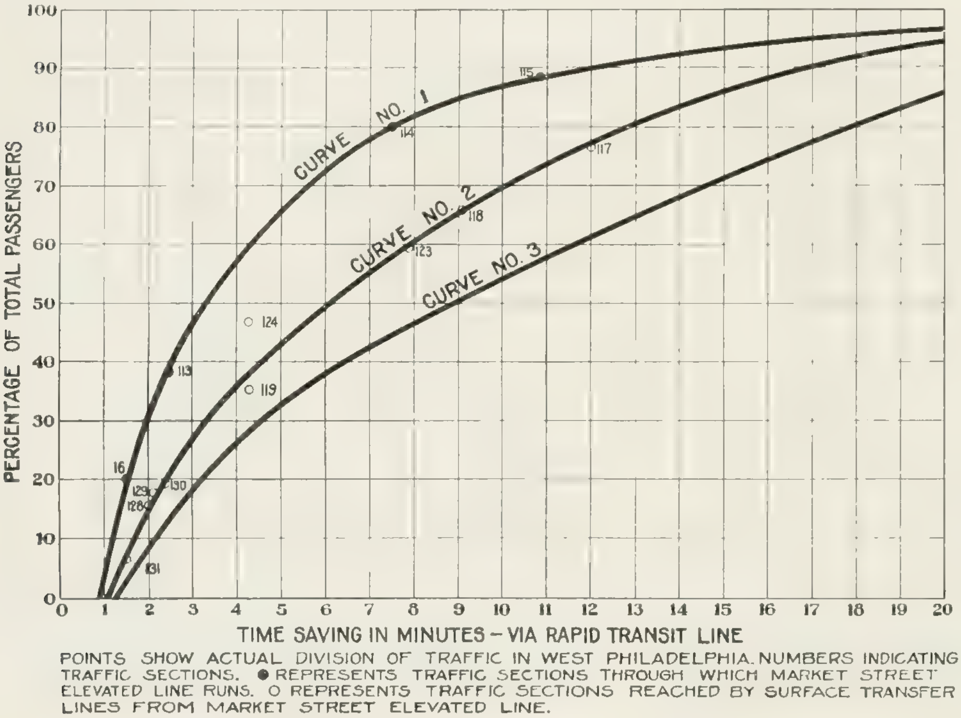


FIG. 14—RELATION OF PASSENGERS USING RAPID TRANSIT LINES TO TIME SAVING

Curve No. 1—For traffic between delivery district and sections on rapid transit line.
Curve No. 2—For traffic between sections requiring extra transfer by rapid transit line.
Curve No. 3—For traffic between sections requiring two extra transfers by rapid transit line.

In making use of these curves it must be continually borne in mind that all attendant conditions must be substantially equivalent to those in the territory served by the Market Street line. The frequency of service on the high-speed line, and the space and degree of comfort provided must be at least as favorable to the high speed line in comparison with surface lines serving the same territory as was the case in West Philadelphia at the time of the survey. It must be observed that surface transfer lines are as close together, and the average walk required not more than in West Philadelphia.

TABLE III—DIVISION OF LOCAL TRAFFIC IN WEST PHILADELPHIA.

Length of Journey	Distance Center to Center (Miles)	Average Time Saving (Minutes)	Proportion Diverted to Rapid Transit Line (Percent)
Within each section	..	0.0	5
One section to the next	1	1.5	15
One section to second distant.	2	5.0	43
One section to third distant..	3	8.5	63
One section to fourth distant.	4	12.0	77
One section to fifth distant...	5	15.5	87
One section to sixth distant..	6	19.0	93

Division of Local Traffic—Table III gives the proportions used in estimating the local traffic between sections through which the proposed rapid transit lines pass. It is based upon actual division of traffic in West Philadelphia. The time saving given allows time for ascending stairs. Equivalent proportions of rapid transit traffic are taken from the middle curve, except in the first two cases. For local traffic of sections reached by surface transfer, the time saving is approximately the same as for the adjoining sections on the rapid transit line; therefore the same ratios have been used excepting where there is a direct surface line between sections under consideration.

Rules for use of Diagram—From the above data based upon actual conditions in West Philadelphia the following rules were drawn up for using the percentage curves of rapid transit and for otherwise estimating the proportion of present traffic which would be diverted to the proposed rapid transit system.

RULES FOR ESTIMATING RAPID TRANSIT TRAFFIC.

1—Between sections directly on rapid transit line and section 15-B (Central Delivery District), use average time saving as determined for section and read percentage from curve *No. 1*, as shown in Table IV.

TABLE IV—METHOD OF USING CURVES OF FIG. 14 FROM SECTION 26 TO SECTION 15-B

Average Time Saving (Minutes)	Traffic diverted to Rapid Transit		Total Surface Passenger Year 1913	Est. Rapid Transit Passengers (82 Percent)
	Curve No.	Per Cent		
8.1	1	82	[illegible]	1 771 [illegible]

TABLE V—METHOD OF CALCULATING TRAFFIC BETWEEN SECTIONS ON THE SAME RAPID TRANSIT LINE

To Section	Average Time Saving Minutes	Traffic Diverted to Rapid Transit		Total Surface Passengers Year 1913	Est. Rapid Transit Passengers
		Curve No.	Per Cent		
26	1.3	2	5	634 775	31 700
30	2.1	2	15	665 343	99 800
34	5.0	2	43	266 970	114 800
42	8.5	2	63	115 379	72 700
21	2.1	2	15	674 177	101 100
18	5.0	2	43	1 073 316	461 500
15-c	6.5	2	53 *	217 343	115 200

*As Section 15-C is a fractional section lying between Sections 18 and 15-B, 53 percent was used, viz.: $\frac{43 + 63}{2} = 53$.

2—Between sections directly on the rapid transit line and other sections on the same rapid transit line, use percentages given in Table V for local traffic. As an example of where this rule would hold may be cited the trip from Sectioon 26 to other Sections on N. Broad street line. (See Fig. 15).

4—On a through routed rapid transit line, if there be no reverse movement add time saving of sections under consideration; plus two minutes that has been allowed for reaching street; plus one minute if there is no direct surface line. Count number of transfers required by surface and by rapid transit, allowing one minute each for transfers. Consider originating section on rapid transit line as transfer section. Deduct present transfer if any and use curve indicated by difference.

An example of such a calculation is shown below between Section 26 (North Broad) and Section 8 (South Broad). This is also shown in Fig. 17.

	Average Time Saving (Minutes)
From Sec. 15-B to Sec. 26	[illegible]
From Sec. 15-B to Sec. 8	[illegible]
Add allowance for reaching street in Sec. 15-B	[illegible]
Total	13.7
Deduct transferring in Sec. 15-B	2.0
Net average Time Saving	11.7

	Transfers Required
Proposed Rapid Transit (Considered in Section 15-B and 26)	2
Present surface (direct line)	0
Difference	2

11.7 mins. read on Curve *III* = 61 percent of present traffic diverted to rapid transit.

A second example of this type is given below for the trip between Section 29 (North Broad) and Section 9 (South Broad). This is also shown in Fig. 18:—

	Average Time Saving (Minutes)
From Sec. 15-B to Sec. 29	10.5
From Sec. 15-B to Sec. 9	3.1

FIGS. 15, 16 AND 17—EXAMPLES OF DIVISION OF LOCAL TRAFFIC

Fig 15—Traffic section No. 26, to other sections on North Broad street line. Fig. 16—Where there is a direct surface line. Percentage used to next section nearer originating section. Fig. 17—Where there is no reverse movement as between section 26 (North Broad) and section 8 (South Broad); as between section 29 (North Broad) and section 9 (South Broad). If there is a reverse movement, as between section 29 (North Broad) and section 7 (South Broad); as between section 26 (North Broad) and section 14-C (Frankford).

3—Between local sections reached by surface transfer from rapid transit line, use same percentage as to adjoining section along rapid transit line, except where there is a direct surface line; in which case use percentage used to next section nearer originating section. (See Fig. 16 and Table VI.)

TABLE VI—METHOD OF CALCULATING TRAFFIC BETWEEN LOCAL SECTIONS REACHED BY TRANSFER FROM RAPID TRANSIT LINES.

From Section No. 26	Percent Traffic Diverted to Rapid Transit	Curve
To Sec. 68 (no direct line)	63 .... (Same as 42)	2
To Sec. 67 (direct line)	15 .... (Same as 30)	2
To Sec. 33 (direct line)	15 .... (Same as 30)	2

Note—Sections farther removed from rapid transit line treated same as adjoining section nearer rapid transit line.

Add allowance for reaching street in Sec. 15-B	2.0
Total	[illegible]
Deduct transferring in Sec. 15-B	2.0
Remainder	13.6
Add for transfer account no direct surface route	1.0
Net average time saving	14.6

	Transfers Required
Proposed rapid transit (considered in Sections 30, 15-B and 8)	3
Present surface (no direct line)	1
Difference	2

14.6 mins. read on Curve *III* = 70 percent of present traffic diverted to rapid transit.

If there be a reverse movement, calculate difference in time, at present and by proposed system, count transfers as above and use curve indicated as shown below for the trip between Section 29 (North Broad) and Section 7 (South Broad). See Figs. 18 and 19.

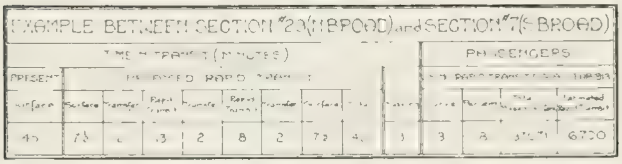
Explanation—Passengers originate in section 29 on the Erie Avenue surface feeder line and transfer from that line to the North Broad street line at Broad street and Erie avenue; thence via the Broad Street line to Section 8, transferring to and reaching destination, Section 7, via the Snyder Avenue surface line. The "Present" or surface route from Section 29 to Section 7 is direct or continuous via Fifth street. Therefore it was only necessary to determine the running time from the centre of Section 29 to the center of Section 7 which from the schedule in effect on that route was found to be 45 minutes or a saving via proposed rapid transit of three minutes.

5—To transfer rapid transit lines, if there be no reverse movement, add time saving to center of city plus one minute if there is no direct surface line, count transfers as above and use curve indicated. If there be a reverse movement, calculate difference in time by present surface and by proposed rapid transit system as shown below, count transfers as above and use curve indicated as shown below and in Fig. 19 for the trip between Section 26 (N. Broad) and Section 14-C (Frankford).

Explanation—Passengers originating in Section 26 on the North Broad Street line transfer (in central delivery district—Section 15-B) to and reach destination Section 14-C via the Frankford line.

Cases were found which required separate treatment because of peculiar features; some of which were:—

a—Irregular position of section with regard to rapid transit line.
b—Poor delivery by surface transfer line.
c—Diagonal route by present surface.



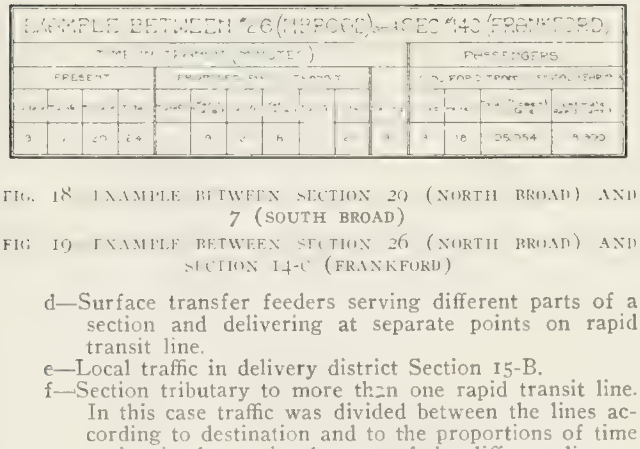


FIG. 18 EXAMPLE BETWEEN SECTION 29 (NORTH BROAD) AND 7 (SOUTH BROAD)

FIG 19 EXAMPLE BETWEEN SECTION 26 (NORTH BROAD) AND SECTION 14-C (FRANKFORD)

d—Surface transfer feeders serving different parts of a section and delivering at separate points on rapid transit line.
e—Local traffic in delivery district Section 15-B.
f—Section tributary to more than one rapid transit line. In this case traffic was divided between the lines according to destination and to the proportions of time saving in the section by way of the different lines.

CALCULATION OF RAPID TRANSIT TRAFFIC BY TRAFFIC SECTIONS

A statement was prepared (See No. 19 for Sec. 26) for each traffic section on which the total yearly passengers to each other traffic section was listed. Applying the appropriate percentage that would use the rapid transit line as calculated on the time saving basis gave the estimated rapid transit passengers. The total passengers originating in section 26 was 12 997 901, of whom 9 296 241 were destined to sections having an average time saving by the proposed rapid transit lines over the present surface system, and 47 percent of the 9 296 241 would use the proposed rapid transit lines on account of time saving in transit based on percentages as derived from the present Market Street subway-elevated line from West Philadelphia. The total time saving in minutes is obtained by multiplying the estimated rapid transit passengers by the time saving in each case.

Summary of Traffic of One Section—Taking traffic Section 26 of the North Broad Street group as an example, it was found that the movements of traffic between that section and fifty-three other traffic sections would be influenced by the proposed rapid transit lines. The total traffic one way represented by these movements amounted to 9 296 241 for year to June 30, 1913. The portion of this traffic which would be diverted from the present system to the proposed rapid transit system was estimated for each movement and totaled 4 393 700 for the section. Of this amount 3 220 500 was destined to other North Broad sections, and the reverse movement to Section 26 is covered in the estimate of those sections.

The rapid transit traffic destined to sections served by other rapid transit lines, amounting to 1 173 200 for the year ending June 30, 1913, was doubled, thereby accounting for the reverse movement on the North Broad Street Line. The calculation of total rapid transit traffic is shown in Table VII.

TABLE VII—RAPID TRANSIT TRAFFIC OF SECTION 26 NORTH BROAD.

Rapid transit passengers originating in Sec. 26.....	4 393 700
Destined to North Broad sections................	3 220 500
Destined to sections also tributary to other lines...	1 173 200
Add for reverse movement......................	1 173 200
	2 346 400
Add destined to other North Broad sections.......	3 220 500
	5 566 900
Add traffic to Sec. 15-B for reverse movement......	1 771 500*
Total traffic Sec. 26.........................	7 338 400

*Estimate of traffic from Section 15-B not used in estimates of tributary traffic.

Summary of Rapid Transit Traffic by Lines—A summary (See Page 175, Vol.-1-1913 Report for Statement No. 19) was then made of the results obtained from all sections. This is a grouping by case number (explained below) and letter (as explained in Statements No. 19 and 20.) Statement No. 20 is a composite summary of the summaries as shown under statement No. 19 with the passenger totals listed on horizontal lines by proposed rapid transit lines and in columns as using present surface (origin) or (delivery) lines—Market Street subway-elevated—proposed North Broad Street line (or rapid transit line of origin) and the combined other rapid transit lines. The case numbers designate a classification of passengers made for convenience, and are defined as follows:—

Case I—Passengers originating on a rapid transit line and destined to a point on a rapid transit line.
Case II*—Passengers originating on a rapid transit line and destined to a point on a surface feeder line.
Case III*—Passengers originating on a surface feeder line and destined to a point on a rapid transit line.
Case IV—Passengers originating on a surface feeder line transferring to a rapid transit line and destined to a point on a surface feeder line.

Under the four cases all passengers using the various routes and also the passenger mileage shown

*Case II rides became Case III in return movement and vice versa.

on Statement No. 20 (with the exception of those destined to points on North Broad Street line under Cases *I* and *III* and those destined to points reached by surface transfer from North Broad Street line under Cases *II* and *IV*) have been doubled which is fairly assuming that the same return movement takes place. Statement No. 20 represents 30 048 573 passengers originating in sections through which the proposed North Broad Street line operates or within the time saving area of that line; 7 313 585 of these passengers are destined to sections outside the time saving influence of the North Broad Street Line. Therefore 7 313 585 passengers are doubled and added to 30 048 573 passengers making a total of 37 362 158 passenger movements in both directions on the proposed North Broad Street line, 37 362 000 being posted on Statement No. 25 as the 1913 tributary rapid transit passengers—direct or by transfer from surface railway territory.

As an example (of doubling), to explain the method of arriving at passengers on Statement No. 20 entered in columns other than North Broad Street column, under *Case I* for South Broad Street, 1 404-900 passengers originated in sections through which the North Broad Street line operates and traveled to sections served—directly or intersected by the South Broad Street line. This is a one direction movement and assuming that they returned, the number was doubled for both directions and 2 809 800 passengers entered in North Broad column, and also in the other rapid transit column, as they traveled over both North and South Broad Street lines in both directions.

Results of Estimates by Rapid Transit Lines—Similar estimates of all sections were compiled and totaled and the result showed that the traffic diverted from the surface system by the North Broad Street line would be, for year June 30, 1913, 37 362 000 passengers both ways.

The passengers diverted from the surface system by the other proposed rapid transit lines are estimated as follows:—

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

The passengers diverted from the steam railways, as explained later, were for year ending June 30, 1913, by lines as follows:—

[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

The total passengers tributary to the proposed rapid transit system, direct or by transfer, as estimated for year to June 30, 1913, were as follows:—

North Broad Street line	[illegible]
South Broad Street line	15 156 000
[illegible]	[illegible]
[illegible]	[illegible]

Passenger Mileage—In all revenue calculations in the report, the fare of passengers using transfers either with high-speed or surface lines is divided according to the mileage traveled on each. For each section, statements were prepared listing horizontally the sections to which there were estimated rapid transit passengers, and in columns headed same as Statement No. 20 was listed the distance from center to center of section of origin and section of destination. This distance multiplied by the number of passengers gives the passenger mileage. For example, from the center of Section 26 to the center of Section 12 is four miles. The estimated rapid transit passengers, on North Broad Street (140 200) was multiplied by the distance, three miles, and the answer to the nearest thousand, 421 000 passenger miles, was entered under North Broad. One mile ride per passenger on South Broad, or 140 000 passenger miles, was also entered under other rapid transit. Summarizing the passenger mileage, the same as the passengers, the entries were then made on Statement No. 20 and the passenger mileage percent calculated for each case by lines, as follows for *Case I* South Broad:—

Total other passenger mileage 5 [illegible] [illegible]
Total passenger mileage......12 458 000
under other rapid transit lines and the balance 59 percent. entered under North Broad Street line.

Summary of All Tributary Traffic, Statement No. 21—A summary of the traffic tributary to each of the recommended rapid transit lines was compiled by traffic sections to show the relative traffic and estimated division according to distance from the center of the city. For the North Broad Street line, the distance to the center of the section from Market Street is the average distance from Eleventh and Market Streets via recommended rapid transit line and the surface transfer feeder lines. The population is shown on Map No. 29, and the method of estimating (obtained by counting spots on population map) has been explained. The surface passengers originating (estimate based upon traffic survey) are the total passengers originating in each traffic section and for traffic section 26 were obtained by summarizing the totals of all the third column (or yearly) passengers shown in each traffic section on map 31. This total for map 31 represents the yearly surface passengers originating in traffic section 26 with destination as shown by Table VIII.

As a check the same total was secured by summarizing the grand totals (From section 26) for the 23 lines operating through Section 26 as illustrated on statement 18 for Cumberland Street line, route 19—Grand total 430 824, checking summary as in Table IX.

The estimated rapid transit passengers originating was obtained from Statement No. 20 (composite summary) representing 30 048 573 passengers originating in all sections through which the proposed North Broad Street Line operates or within the time saving area of that line, less 6 632 513 from the central delivery district (Sec. 15-B) as explained by foot note *B*, with the following differences making up the additional 300 040 as shown by total of 23-716 100 on statement 21:—

The original calculations were based upon a continuous [illegible] line in Broad street [illegible]. With the

Northeast Boulevard elevated branch, Section 35 would be listed with "Traffic Sections Served Directly," and, on account of this direct service and additional time-saving, the estimated rapid transit passengers would be 554 900 as shown on statement 21, instead of 254 900. Also in making up statement 20, the estimated rapid transit passengers for Section 31 is 100 260, while on statement No. 21 this was shown to the nearest hundred as 100 300. Therefore, with corrections, statement 20 would represent 30 348 613 passengers for North Broad Street line, including 6 632 513 from Section No. 15-B (Central delivery district), which as shown by foot note *B* is not considered in treating statement 21. For example:

Total of the four cases destined to North Broad street line and shown in column "Using North Broad Street Line" (Statement No. 20)	30 048 573
Subtract for Section No. 15-B (Statement No. 21)	6 632 513
Remainder	23 416 060
Add for Section 35 (Additional)	300 000
Add for Section 31 (Additional)	40
Total as shown on Statement No. 21	23 716 100

The last three columns of statement 21 are derived as follows, using 15-C the first section shown:—

A—Population 17 800
B—Surface passengers originating 3 474 200
C—Estimated rapid transit passengers originating. 683 800

$\frac{B}{A} = \frac{3\,474\,200}{17\,800} = 195$, surface passengers originating per capita.

$\frac{C}{A} = \frac{683\,800}{17\,800} = 38$, estimated rapid transit passengers originating per capita.

$\frac{C}{B} = \frac{683\,800}{3\,474\,200} = 19.7$ percent (reduced to 19.5 percent) ratio of estimated rapid transit to present surface passengers.

Steam Railroad Passengers The steam railroad passengers of 1913 as shown on Statement 25 were calculated as follows:—

On the Philadelphia & Reading Railway the excursion fare between Logan and Reading Terminal is 12.5 cents, and the time 19 minutes, using the third fastest train. By proposed rapid transit the fare would be five cents and the time of transit 23 minutes. Adjusting the steam time to difference in fares saved at rate of one cent to four minutes, would result in a difference in fares of 12.5 cents minus five cents, or 7.5 cents, and this multiplied by four equals 30 minutes, plus 19 minutes actual steam time in transit, or 49 minutes. Deducting 23 minutes, the rapid transit time of transit would equal a saving in time by rapid transit of 26 minutes and reading from Fig. 14 of this article at the intersection of the 26 minute line and the middle or curve *No. 2* (as one transfer is involved) would indicate that 95 percent (all time savings above 20 minutes read at 95 percent) of the 85 566 total passengers from this station, or 81 288 passengers, would be diverted to the proposed rapid transit line.

The same procedure was followed with respect to commutation fares.

Terminal and Connecting Line Passengers —The terminal and connecting line traffic as shown on statement 29, for the South Broad Street Line was determined by traffic count either on the cars of the suburban lines, the same as for the Philadelphia Rapid Transit lines, or by a count of all passengers at point of delivery to the Philadelphia Rapid Transit cars. On the Southwestern Line to Essington and Bow Creek, a total of 216 000 yearly passengers originated outside the Philadelphia city limits (including Fort Mifflin and Point Breeze Park) and were so delivered. Assuming that the same return movement takes place, this amount was doubled, or in round numbers 400 000 added to the 585 000 estimated rapid transit passen-

TABLE VIII SUMMARY OF TRAFFIC BY DESTINATION.

Destination by Traffic Section No.	Yearly Surface Passengers Originating	Destination by Traffic Section No.	Yearly Surface Passengers Originating	Destination by Traffic Section No.	Yearly Surface Passengers Originating
2	29 129	34	266 970	89	7 200
7	50 520	35	23 077	90	12 000
8	238 953	40	11 687	91	21 345
9	30 042	41	34 023	94	151 108
11	28 158	42	115 379	95	256 723
12	274 888	43	126 385	96	31 371
13	83 537	45	11 605	97	70 243
14	1 024 675	52	29 636	98	55 248
15	2 462 880	55	48 417	103	71 724
16	55 793	56	15 300	104	178 206
17	105 773	57	69 044	105	86 905
18	1 073 316	58	43 294	107	44 378
19	339 519	60	15 657	113	50 285
20	572 118	61	7 900	114	15 389
21	674 177	63	49 414	115	16 660
22	148 887	65	15 784	117	3 532
23	13 331	66	33 884	118	74 203
24	106 358	67	262 413	119	50 466
25	621 530	68	21 991	120	28 065
26	634 775	70	62 893	123	1 583
27	656 697	71	67 110	124	4 097
29	125 970	72	30 600	127	4 800
30	665 343	74	94 048	128	3 400
31	4 201	78	55 661	129	24 980
32	26 632	80	2 000	130	7 333
33	145 757	82	17 526	131	2 000
				Total	12 997 901

TABLE IX—YEARLY PASSENGERS ORIGINATING IN SECTION 26.

On Route No.	Direct	Transfer	Total
2	1 038 400	150 600	1 189 000
6	1 037 640	281 645	1 319 285
8	18 076		18 076
16	8 500	2 300	10 800
19	384 719	46 105	430 824
20	548 886	118 772	667 658
21	625 300	265 100	890 400
22	353 300	50 900	404 200
23	266 200	36 500	302 700
231	247 400	16 000	263 400
24	66 307	16 202	82 509
241	494 200	76 600	570 800
25	398 338	72 213	470 551
251	275 783	26 265	302 048
47	349 384	27 053	376 437
49	395 000	283 600	678 600
53	512 200	78 900	591 100
54	934 238	275 395	1 209 633
55	82 847	13 970	96 817
551	821 945	57 805	879 750
60	443 821	464 632	908 453
601	148 866	337 234	486 100
69	558 948	289 812	848 760
	10 010 298	2 987 603	12 997 901

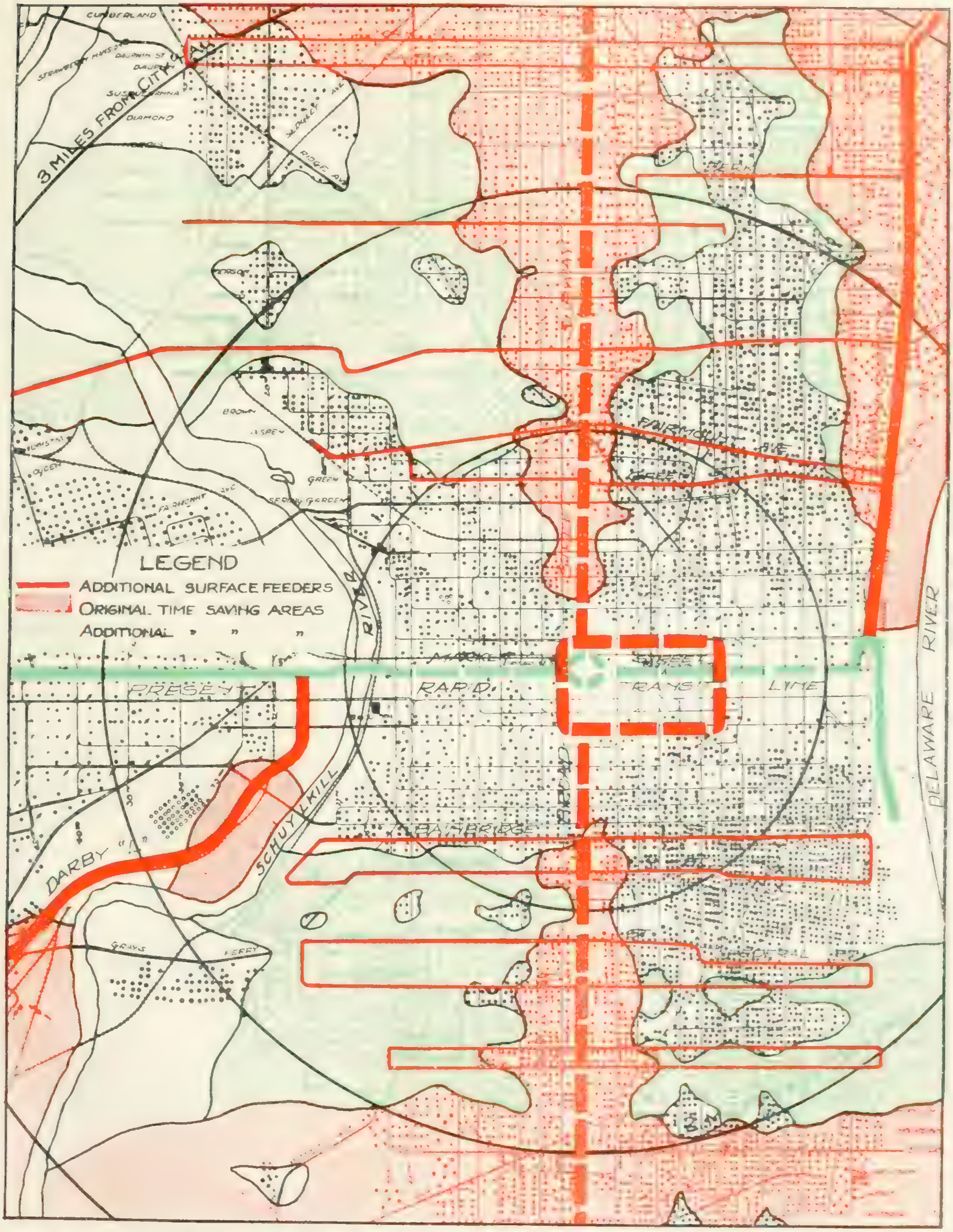


FIG. 20—ILLUSTRATION OF ENLARGEMENT IN TIME SAVING AREAS RESULTING FROM PRINCIPAL SURFACE TRANSFER FEEDERS WITHIN THE AREA OF THE THREE MILE LIMIT ORIGINALLY INCLUDED. SCALE [illegible] MILE

FIG. 25—METROPOLITAN AREA OF PHILADELPHIA. SCALE $1\frac{3}{4}$ IN. = 1 MILE

NOTE—We are advised that a limited number of copies of Vols. I and II, Report of Transit Commissioner, City of Philadelphia, July, 1913, are still available for distribution and that the Dept. of City Transit will honor requests for such copies from those entitled to receive them who are seriously and technically interested in the problem. Vol. I contains 266 pages of printed matter and Vol. II is made up of 69 large folding maps and diagrams, many of them in colors. This sheet gives a somewhat inadequate idea of the elaborateness of the plates comprising Vol. III.—(Ed.)

gers originating in Section 2, or at League Island, making a total of 985 000 terminal and connecting line passengers for South Broad Street line.

Estimated Rapid Transit Rides per Capita—Dividing the total passengers, 43 486 900 diverted from surface and steam railways by the population (449-700) in all traffic sections wholly or partly within the area of time saving from the delivery district results in the estimated rapid transit rides per capita of 96.7.

TIME SAVING AND TRAFFIC RESULTING FROM ADDITIONAL SURFACE TRANSFER LINES

In the rapid transit system on which the above estimates of traffic were based, the surface transfer privilege was originally limited to outlying lines. The purpose of this was to avoid congestion of the expensive high speed lines by short riders to and from the central delivery district, who are already well served by surface lines.

It will be noted that on the North Broad Street line no surface transfers were originally proposed south of Lehigh Avenue, a distance of approximately three miles from the center. On the Frankford line there was none south of Front Street and Kensington Avenue, which is also practically three miles from the center, except that transfers were originally proposed with the easterly ends of the Norris Street line and the Girard Avenue lines, in order to serve properly the outlying territory along Richmond Street. On the Darby line the nearest transfer line was shown at Forty-ninth Street about three miles from the City Hall. On the South Broad Street line, however, transfer was provided with the Snyder Avenue line about two miles from the center. This was due to the shortness of the South Broad Street line and to the small present development south of Oregon Avenue (2.5 miles from the center), on which street a new cross town line is suggested after the present steam railroad tracks are removed. The time saving contours for this system are shown for each five minutes on map No. 26 (Trans. Comm. 1913 Report) and the resulting areas of time saving shown in full colors, the value represented by each being as follows:—

Pink	0 to 5 minutes
Green	5 to 10 minutes
Orange	10 to 15 minutes
Blue	15 to 20 minutes
Yellow	20 to 25 minutes
Purple	25 to 30 minutes
Brown	30 to 35 minutes

The limitation of transfer privileges described above restricts the movement of the population within the zone around the central delivery district. As there would be little or no time saving to and from the central delivery district, the surface lines will continue to be used for such journeys, but for movements to all other parts of the city, the people of this populous zone should have the high speed facilities.

Present Agreement on Transfers—In the tentative agreement reached between representatives of the City and the Philadelphia Rapid Transit Company, it is therefore provided that free transfers shall be given between surface lines and high speed lines at *all* stations. All calculations used in the Transit Commissioner's Report and referred to herein are based on the original premises that no free transfers with surface lines would be made in the district bounded by Lehigh Avenue, Front Street, Snyder Avenue and the Schuylkill River, and the resulting time saving areas from central delivery district are shown in pink on accompanying Fig. 20.

The areas shown in green on Fig. 20 show the extension of the above time saving areas from the central delivery district only, which would result, if additional surface transfer lines within the three mile area and intersecting the high speed lines at stations were included in the rapid transit system as surface feeders. These additional surface transfer lines are also shown in Fig. 20. The areas remaining uncolored are still outside of the influence of the rapid transit lines in respect to the central delivery district.

The surface transfer lines, the addition of which produces the above extension of time saving areas are:—

1—York and Dauphin street west of Front street transferring with Frankford elevated.
2—Berks street west of Front street transferring with Frankford elevated.
3—Columbia avenue transferring with North Broad street line.
4—Girard avenue west of Front street transferring with Frankford elevated and North Broad street line.
5—Green and Fairmount transferring with Frankford and North Broad street lines.

The following lines were added as transfer lines in connection with the South Broad Street line.

1—Catharine and Bainbridge.
2—Federal and Wharton.
3—Morris and Tasker.

The increase in traffic tributary to the proposed rapid transit lines, and which is obtained by these additional surface transfer lines, is as follows for the year to June 30, 1913:—

North Broad street line	4 982 200
South Broad street line	2 883 000
Frankford line	[illegible]

Including the traffic resulting from these additional surface transfers, the number of passengers using the various proposed lines for the year to June 30, 1913, would be:—

North Broad street line	48 469 100
South Broad street line	18 030 000
Frankford line	21 802 700
Darby line	11 523 800

DIAGRAMS ILLUSTRATING RAPID TRANSIT TRAFFIC

Traffic Diagrams illustrating graphically the "In-" or city-bound estimated rapid transit traffic were prepared for each of the proposed lines. Referring to Map No. 33 (Report of Transit Commissioner), South Broad Street line (referred to for convenience on account of few sections) a red band begins at League Island and in yearly passengers represents 584 000 at the 3.5 mile circle; 604 000 at the 2.5 mile circle; 5 255 000 at the 1.5 mile circle; 6 900 000 at the 0.75

mile circle and at City Hall or central delivery district 7 201 000. The branch arms or extensions at Snyder Avenue represent transfer passengers—the small threads from the Rapid Transit line to the surface lines toward the Delaware River 4 000 and toward Point Breeze Avenue 9 000. The thicker branches represent transfer passengers from the surface lines to Rapid Transit line at Snyder Avenue; from the direction of the Delaware River 541 000 and from the direction of Point Breeze Avenue 421 000. In all cases the direction of transfer passengers may be determined by the direction of the curve at the junction with the main trunk.

In Section 8, between the 2.5 and 1.5 mile circles, 138 000 passengers are discharged as represented by the small offset shown between Wolf and Jackson Streets and 3 840 000 are picked up as represented by the additional width shown between Snyder Avenue and McKean Street. The continuous band shown between the points of transfer passengers discharged and those picked up, or between Jackson Street and Snyder Avenue represents 453 000 through passengers or passengers riding through (Section 8) the zone between the 2.5 and 1.5 mile circles and originating in Sections 2 and 5, or before the 2.5 mile circle is reached. In Section 12 between the 1.5 and 0.5 mile circles 266 000 passengers are discharged as represented by the offset at Ellsworth Street and 1 911 000 are picked up as represented by the additional width at the mile circle. The band between Ellsworth Street and the mile circle represents 4 989 000 through passengers of those originating in Sections 2, 5 and 8. In section 15-A, between Lombard and Latimer Streets, 102 000 passengers are discharged as represented by the offset at Pine Street and 403 000 passengers are picked up as represented by the additional width at Spruce Street, the band between Pine and Spruce Streets representing 6 798 000 through passengers of those originating in Sections 2, 5, 8 and 12.

In Section 15-B, between Latimer and Cherry Streets, 2 846 000 passengers are discharged, 228 000 of whom originated on the Snyder Avenue surface transfer line and are classed as *Case III* passengers. In Section 15-B, 4 355 000 passengers transfer to other rapid transit lines as follows:—

1—1 094 000 to the east, 367 000 represented by the offset between Fourth and Fifth streets being discharged in Section 14-B and the remainder, 727 000, along the line of the Frankford "L."
2—1 757 000 to the North Broad street line.
3—1 504 000 to the west divided, i. e., 864 000 to the present Market street subway-elevated and 640 000 to the proposed Darby line.

This information was obtained by summarizing the estimated rapid transit passengers as shown on Statement No. 19 for South Broad Street sections 2, 5, 7, 8, 9, 12 and 15-A and similar information may be obtained by a like method for any district of the city and in any direction.

These are the base figures upon which all estimated operating statistics and results from rapid transit lines recommended for immediate construction (Statements No. 25 to 40) are based.

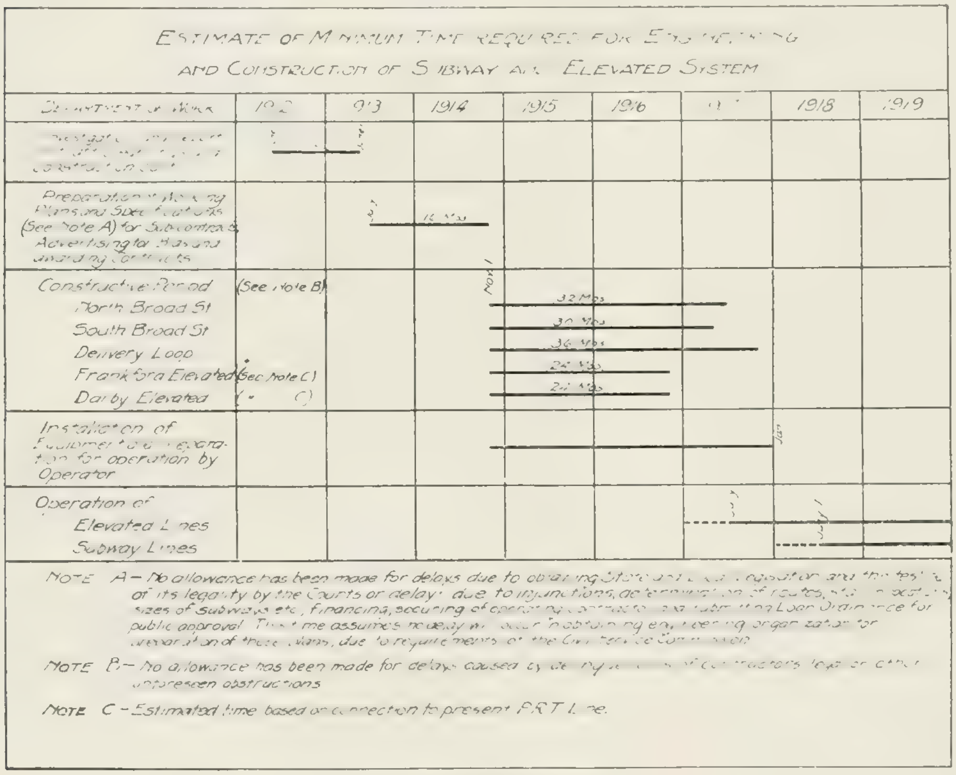


FIG. 21—PROGRESS CHART

ESTIMATES OF CONSTRUCTION COST

Preliminary Designs—Plans, profiles and all necessary detail drawings were prepared on which to base estimates of cost of various types of construction and various routes for the proposed facilities. A large number of estimates of cost were then prepared for building the subways with different cross-sectional areas and different clearances and types of roof and side wall construction. The height assumed from top of rail to underside of roof varied from 12 to 15 ft.

General Design Adopted—As the result of these comparative estimates and the study of rapid transit practice and conditions, locally and elsewhere, it was decided to recommend the use of a car about 50 ft. long, 8 ft.-9 in. wide, 11 ft.-8 in. high and to make the clear height of the subways 12 ft. from top of

rail to underside of roof;* also to make the cars with longitudinal seats entirely, as the average length of ride will be comparatively short. All cars are estimated as motor cars with two 125 horse power motors per car. The elevated lines are to be built with solid floors to conform to best modern design. All lines are

TABLE X—UNIT PRICES* USED IN OBTAINING CONSTRUCTION COST ESTIMATES

Construction Items and Units of Measure	Central Delivery Loop	SUBWAY North Broad: Olney to Allegheny	SUBWAY North Broad: Allegheny to Race	SUBWAY South Broad: Spruce to McKean	SUBWAY South Broad: McKean to Bigler	OPEN CUT Bigler to Navy Yard	ELEVATED Elevated Structures Frankford, Darby, 16th St., Boulevard
Excavation, Earth, per cu. yd.	$4.50 } unclassified	$2.25	$2.7[illegible]	$3.50 below water; 2.50 above water			
" Rock, per cu. yd.	4.[illegible] }	4.00	4.[illegible]				
" Tunnel in earth, per cu. yd.	6.50				2.50		
" Open cut in earth, per cu. yd.						$0.30	
Concrete, Subway, elevated, per cu. yd.	$10.00	$8.50	$8.[illegible]	$10.00 below water; $[illegible] above water			$[illegible]
" Retaining walls, per cu. yd.					$8.50	$8.00	7.50
" Footings for elevated, per cu. yd.						$[illegible]	[illegible]
Steel, structural and reinforcing. Price per ton	$70.00	$70.00	$70.00	$70.00	$7[illegible]	$7[illegible]	$70.00
Back fill—Subway, per cu. yd.	$0.25	$0.25	$0.25	$0.25	$0.25		
Sewers, Excav. including back fill, per cu. yd.	$ 3.00	$ 3.00	$ 3.00	$ 3.00	$ 3.00		$10 [illegible]
" Brick masonry, per cu. yd.	12.00	12.00	12.00	12.00	12.00		
" Concrete masonry, per cu. yd.	12.00	12.00	12.00	12.00	12.00		
" Cast iron—special, per ton	70.00	70.00	70.00	70.00	70.00		0.50
" Cast iron—straight, per ton	50.00	50.00	50.00	50.00	50.00		
" Laterals, each	10.00	10.00	10.00	10.00	10.00		
" Wellholes, ft. vert. height	10.00	10.00	10.00	10.00	10.00		
" Manholes, each	100.00	100.00	100.00	100.00	100.00		
Removing obstructions, per mile of line							
Chambers for T. C. duct, each	400.00	400.00	400.00	400.00	400.00		
Maintenance and relaying cable conduits, per duct ft.	0.50	0.50	0.50	0.50	0.50		
Furnishing and laying 3" T. C. duct, per duct. ft.	$ 0.10	$ 0.10	$ 0.10	$ 0.10	$ 0.10		
Maintenance of water pipes, per lb.	0.01	0.01	0.01	0.01	0.01		
Furnishing and laying 48" steel water pipe, per ft.	25.00		25.00				
Sump chambers and pumps, each	$ 500.00	2 500.00	2 500.00	2 500.00	2 500.00		
Underdrains—subway, per ft.	1.50	1.50	1.50	1.50	1.50	1.00 including pumps	
Repairs to sidewalks, per sq. yd.	2.00	2.00	2.00	2.00	2.00	2.00	
Resetting curbs—granite, per ft.	0.30	0.30	0.30	0.30	0.30	0.30	
New curb—concrete, per ft.	1.50	1.50	1.50	1.50	1.50	1.50	
Repairs to roadways, per sq. yd.	2.50	2.50	2.50	2.50	2.50	1.50 (macadam)	
Toilet rooms, each	500.00	500.00	500.00	500.00	500.00	1 000.00	
Stair treads, per ft. length of tread	2.50	2.50	2.50	2.50	2.50	2.50	
Railings—light, per ft.	1.50	1.50	1.50	1.50	1.50	1.50	
Railings—heavy, per ft.	2.50	2.50	2.50	2.50	2.50	2.50	
Kiosks, each	1 000.00	1 000.00	1 000.00	1 000.00	1 000.00		
Waterproofing, per sq. ft.	0.25	0.25	0.25	0.25	0.25		
Underpinning, special buildings	Special prices	Special prices	Spe'l pric's	Special prices	Spe'l pric's		
Underpinning, ordinary buildings, per ft.	25.00	25.00	[illegible]	25.00	25.00		
Tiling and decorating stations, each	7 000.00	7 000.00	7 000.00	7 000.00	7 000.00	7 000.00	
Painting stations and kiosks, each	750.00	750.00	750.00	750.00	750.00	750.00	
Piles—wood, ft. of pile						0.40	
Bridges for cross streets, per sq. ft.						[illegible]	
Stations, each						15 000.00 (Superstructure)	$75 000.00 (including steel)
Escalators, equipment plus ft. of rise	9 400.00 + 6[illegible]						
Ventilation chambers, each		[illegible]000.00	5 000.00	5 000.00	5 000.00		
Equipment:							
Track construction, per ft.	$ 6.00	$ 6.00	$ 6.00	$ 6.00	$ 6.00	$ 3.00	$ 3.00
Third rail, per mile	5 500.00	5 500.00	5 500.00	5 500.00	5 500.00	5 500.00	5 500.00
Signals, per mile of track	6 000.00	6 000.00	6 000.00	6 000.00	6 000.00	6 000.00	5 000.00
Lighting, each station	2 750.00	2 750.00	2 750.00	2 750.00	2 750.00	2 000.00	1 500.00
Lighting, per ft. of track	0.25	0.25	0.25	0.25	0.25		
Station equipment, each	5 000.00	5 000.00	5 000.00	5 000.00	5 000.00	2 500.00	
Cars, each	12 000.00	12 000.00	12 000.00	12 000.00	12 000.00	12 000.00	12 000.00
Feeders, per car	1 000.00	1 000.00	1 000.00	1 000.00	1 000.00	1 000.00	1 000.00
Sub-stations, per car	2 400.00	2 400.00	2 400.00	2 400.00	2 400.00	2 400.00	2 400.00
Car houses, yards, shops, offices, per car	2 000.00	2 000.00	2 000.00	2 000.00	2 000.00	2 000.00	2 000.00

*To all prices given, except under "Equipment," add 30 percent for subway construction, and [illegible] percent for elevated construction, to "Equipment" prices add 20 percent.

to be fully equipped with signals and all auxiliary apparatus.

Time Allowed for Construction.—The dates on which the recommended lines were assumed to be in operation and the time schedule for their construction and equipment, are shown on Fig. 21.

Unit Prices—The unit prices used in estimating construction costs were taken from the prices bid on similar classes of work in the building of the New York, Brooklyn, Boston and Philadelphia systems and modified to meet the present local conditions. When possible, unit prices for certain items of work were taken from the different municipal departments doing that class of work, viz:—The cost of repaving and building the different types of street pavements was obtained from the Bureau of Highways; the cost of maintaining and building sewers and water pipes was taken from the Department of Public Works, Bureau of Surveys and Water, respectively; the items of con-

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*Since the Transit Commissioner's report was printed it has been decided to design the subway portions of the route with a clear height of 12 ft. 6 in. from top of rail to under side of roof and to provide sufficient clearance and platform length at stations to accommodate trains of eight cars, each 65 ft. long.

crete, steel, excavation, etc., were based mostly on the present bids for similar work in connection with the New York subways and on the actual cost of the present Philadelphia Market Street Subway-Elevated Line. The assessed valuation was used as a basis in determining all property damages.

Table X gives the unit prices used, and by sections to be constructed.

The estimated cost of construction and equipment of the recommended lines as of 1919, the first year of operation, was as shown in Table XI.

TABLE XI—ESTIMATED COST OF CONSTRUCTION AND EQUIPMENT OF RECOMMENDED LINES.

Line	Construction of Way and Structures	Equipment	Real Estate and Easements	Total
N. Broad St. line and delivery loop.	$27 877 000	$6 034 000	$1 725 000	$35 636 000
South Broad St. line.	5 080 000	1 359 000		6 439 000
Frankford line.....	5 625 000	2 402 000	885 000	8 912 000
Darby line........	4 239 000	2 201 000	151 000	6 591 000
Total	$42 821 000	$11 996 000	$2 761 000	$57 578 000

Estimated Cost of Additional Equipment—The estimated cost of additional equipment to be added by years after first year of operation, using North Broad Street Line (including Delivery Loop) as an example, was based on the number of additional cars required on hand (as shown by statement No. 26) at unit prices shown below:—

1920—40 cars @ $14 400 each...$576 000		Sub stations and other equipment appurtenances provided in original construction.
1921—41 cars @ 14 400 each... 590 000		
1922—21 cars @ 14 400 each... 302 000		
1924—43 cars @ $18 500 each... 795 000		Including sub stations and other equipment appurtenances.
1926—39 cars @ 18 500 each... 721 000		
1928—39 cars @ 18 500 each... 721 000		
1930—41 cars @ 19 400 each... 796 000		

ESTIMATED SERVICE REQUIRED.

The service required on the facilities as laid out are calculated by the following method:—

Operation Statistics—Beginning with the 45 903 800 passengers (Statement No. 26) direct or by transfer, as estimated from Statement No. 25 for first year of operation in gradual development of business and dividing by 335, (yearly ratio explained below) which was found to be the ratio of revenue passengers carried on the day of the survey to the total for the fiscal year, results in 137 000 passengers for a normal day and taking 14 percent the ratio of passengers for the maximum hour, one way, to total for the day, results in 19 200 passengers for the maximum hour, one way.

Yearly Ratio—At the time of making the estimates (early in the year 1913) the revenue passengers by lines for the fiscal year to end of June 30, 1913 were available only for the first six months ending December 31, 1912; therefore it was necessary to estimate for the last six months and to do so the following necessary information was secured from the Philadelphia Rapid Transit Company:—

A—Revenue passengers for six months ending 12/31/1911.
B—Revenue passengers for fiscal year ending 6/30/1912.
D—Revenue passengers for six months ending 12/31/1912.
F—Revenue passengers for count day October and November, 1912.

From this the following information was obtained:—

$\frac{A}{B}$ = C, ratio of six months to total for year.

$\frac{D}{C}$ = E, estimated revenue passengers for year ending June 30, 1913.

$\frac{E}{F}$ = yearly ratio.

The method of applying this to determine yearly ratio for Market Street subway-elevated line is:—

$$\frac{A}{B} \quad \frac{16\,704\,327}{34\,041\,755} = 0.481 = C$$

On account of a ticket booth and turnstile being established in October, 1912, at the Juniper street entrance to the subway surface cars and those ticket sales being included with the Market street subway-elevated line for the six months ending December 31, 1912, it was necessary to secure also the number of those ticket sales and deduct same from the Market street subway-elevated in order to determine the true ratio for that line as follows:

D 18 832 345
368 313 (Deducted for Juniper street).
18 464 032

$$\frac{D}{C} = \frac{18\,464\,032}{0.481} = 38\,386\,800 = E.$$

$$\frac{E}{F} \quad \frac{38\,386\,800}{114\,526} = 335, \text{ yearly ratio.}$$

Maximum Load Point—By reference to Map 32 (Transit Commissioners' Report), showing the traffic diagram for the North Broad Street line, it will be noted that the greatest width of ribbon occurs at about Columbia Avenue, which is in Section 21, and represents in yearly passengers 15 825 000, which is 80 percent of the 19 711 000 total one way passengers making up this ribbon. Therefore 80 percent of the 19 200 passengers for the maximum hour, one way, or 15 400 are the passengers passing the maximum load point for the maximum hour. Assuming an average load of 86 per car, the derivation of which is explained later, and dividing 15 400 by 86 results in 179 cars passing maximum load point for the maximum hour. Taking account of the time of round trip, 83.5 percent of the 179 cars, or 149 cars, are required in operation.

The car-hours operated on the composite day of the traffic survey were found to be one three hundred and fiftieth of those during the fiscal year. On this basis there are 8 400 hours for each of the 149 cars, or 1 251 600 car-hours, and applying the service factor of 40 percent (the ratio of the average number of cars in use to the normal maximum number) there are 500 600 car-hours which, divided by 2.5, the average cars per train, results in 200 200 train-hours. Multiplying the 500 600 car-hours by 13.9 miles, the average speed per hour, results in 6 958 300 car-miles, which multiplied by five, the average kilowatt-hours per car-mile, results in 34 791 500 kilowatt-hours.

As stated (in Vol. 1 of Transit Commissioner's 1913 Report) the passenger cars which it was assumed will be operated on these lines have been taken as similar in size to those now in use on the present Market Street line, that is about 50 feet long and having a maximum carrying capacity of 120, based on about four square feet floor area per standing passenger. Since these estimates were made, later investigation

indicates the desirability and probable use of a longer car, which should show a better ratio of operating costs and somewhat reduced cost of equipment.

Margins of Safety—In the use of factors a margin of safety has been introduced either by lowering or increasing the factors developed.

1—Ratio Maximum Hour to Day—From statements similar to Nos. 12 and 13, the passengers for lines tributary to each rapid transit line were summarized by hourly periods and graphic charts prepared for each direction. These charts for the North Broad Street line indicated the maximum rush hour for the surface lines considered to be north bound from 5 to 6 P.M. and the passengers were 22 200, which is 10.3 percent of the total passengers carried for the day on those lines. The ratio of the present Market Street subway-elevated to the surface lines tributary for this period was 1.45, and multiplied by 10.3 gave a modified ratio of 14.9 percent, the ratio of passengers for the maximum hour one-way to the total for the day, which for 1919, the first year of operation, was reduced to 14.0 percent and gradually increased to 14.8 percent at 1930.

Number of Cars Required in Operation—In determining the number of cars required in operation for the North Broad Street Line, the following routing was assumed:—

A—Two-thirds service around delivery loop and to ends of line.

B—One third service via Eighth street to South Broad and to Erie avenue.

	Running Time (Minutes)		Running Time (Minutes)
A—Olney to Erie....	8	B—Erie to Race.....	15
Erie to Race.....	11	Loop via Eighth to South Broad	7
Loop	9½	Same return to Race	7
Race to Erie.....	11	Race to Erie.....	15
Erie to Olney....	8		
	47½		44
Including layover	51	Including layover	48

$$\text{A—}\ \frac{51}{60} = 0.85 \times 2/3 \text{ to Olney} = 0.570$$

$$\text{B—}\ \frac{48}{60} = 0.80 \times 1/3 \text{ to Erie} = 0.265$$

Total....................... 0.835

That is, 83.5 percent is the ratio of cars required in operation to cars passing the maximum load point at the maximum hour.

The details of average speed are as follows:—

Length of route to Olney....................	14.0 miles
Length of route to Erie.....................	9.1 miles
Running time, Olney avenue route............	51 minutes
Running time, Erie avenue route.............	48 minutes

Therefore:—

$$\frac{14 \text{ miles} \times 60 \text{ minutes}}{51 \text{ minutes}} = 16.5 \text{ m.p.h. average speed (Olney)}$$

$$\frac{9.1 \text{ miles} \times 60 \text{ minutes}}{48 \text{ minutes}} = 11.4 \text{ m.p.h. average speed (Erie)}.$$

$(16.5 + 11.4) \div 2 = 13.9$ m.p.h., average speed.

Service Factor—The 40 percent service factor used in determining car-hours was developed as follows:

Cars Per Hour Passing Maximum Load Point	Car-Hours Daily
Morning rush hours—101 cars multiplied by 3 hours of operation, equals	303
10 to 11 A. M.—25 cars multiplied by 3 hours of operation, equals	75
1 to 2 P. M.—[illegible] cars multiplied by 11 hours of operation, equals	[illegible]
Evening rush hours—[illegible] cars multiplied by 3 hours of operation, equals	[illegible]
Total. ..	1 411

1 411 divided by (161 times 24 hours =) 3 860, results in 36.6 percent, which was increased to 40 percent for 1919, the first year of operation to allow a factor of safety, and gradually reduced to 38.2 percent at 1930.

Average Cars per Train—The trains per hour passing the maximum load point are determined as follows:—

	Train-hours Daily
Morning rush hours—20 trains multiplied by 3 hours of operation, equals..........	60
10 to 11 A. M.—8 trains multiplied by 3 hours of operation, equals	24
1 to 2 P. M.—16 trains multiplied by 11 hours of operation, equals	176
Evening rush hours—23 trains multiplied by 3 hours of operation, equals..........	69
Total..........	329

Dividing 1 411, the daily car-hours, by 329 trains per day, resulted in 4.3 average cars per train which was reduced to 2.5 for 1919 the first year of operation and gradually increased to 3.6 for 1913.

Derived Statistics—A value of 24.9 cents revenue per car-mile is obtained by dividing $1 732 900, the revenue as apportioned, by 6 958 300 car-miles; $3.46 is obtained as the revenue per car-hour by dividing by 500 600 car-hours; $11 600 is obtained as the revenue per maximum car operated by dividing by 149 cars required in operation; and $168 200 revenue per mile of line is obtained by dividing by 10.3 miles of line. A value of 6.6 passengers per car-mile is obtained by dividing the 45 903 800 passengers by 6 958 300 car-miles; 308 100 passengers per maximum car operated is obtained by dividing by 149 cars required in operation; and 4 456 700 passengers per mile of line by dividing by 10.3 miles of line.

Also 244 100 car-miles per mile of track is obtained by dividing 6 958 300 car-miles by 28.5 miles of track; 42 400 car-miles per car owned by dividing by 164 cars owned (149 cars required in operation increased 10 percent for spare cars); 5.9 cars owned per mile of track by dividing 164 cars owned by 28.5 miles of track; and 2.3 stations per mile of line by dividing 24 stations by 10.3 miles of line.

ESTIMATED FINANCIAL RESULTS OF OPERATION

The financial results of operation were estimated from the assumed time of commencement to 1930.

Passenger Revenue—The preceding traffic estimates represent the probable volume on the basis of the fiscal year 1913. In projecting the estimates into the future, the probable increase in population in each district served was calculated. The rides per capita per annum, were estimated to increase at the normal rate until the opening of the new facilities. Then the rate of increase was based on the rate of increase actually experienced on the Market Street Line.

Method of Estimating Future Traffic and Revenue—The rate of increase in rides per capita served by the Market Street Line was approximately 18 per-

cent in 1910, the second year of operation of the entire line, and 10, 9 and 8 percent respectively, in the next three years of operation. Due to the fact that the traffic survey was made in the fiscal year 1913, corresponding with the 8 percent rate above, it was determined in the estimates of new rapid transit lines to apply to the number of rides per capita per annum for the first five years of operation a less rate of increase, viz., 7, 6, 5.5, 5 and 4.5 percent respectively. These increases in rides per capita were used in the North Broad Street Line estimates giving rides per capita up to 1924 inclusive. Increases in rides per capita of 4, 3.75, 3.5, 3.25, 3, and 2.75 percent were used for the following years up to 1930.

This gave 110.0 rides per capita for the year 1919 increasing to 176.3 for 1930, which applied to the tributary population estimated for these years, 521 200 and 652 100 respectively, produces rapid transit traffic for North Broad Street Line of 57 379 760 in 1919 and 114 965 200 in 1930 which can be compared with 43 486 900 estimated as of 1913 and with 46 865 465 carried in 1913 by the Market Street Line.

Gradual Development of Traffic—From experience it has been determined that it requires approximately three years for the passengers tributary to a new transportation line to become thoroughly familiar with the use thereof, and from records of such new lines it has been assumed that in the first year of operation only 80 percent of the normal tributary traffic will be secured by the proposed rapid transit lines, in the second year 90 and in the third year 100 percent.

Estimated Revenue and Apportionment—Beginning with 57 379 760, the total passengers, estimated for 1919 on the North Broad Street line, and assuming that 80 percent of these passengers would be obtained in the first year of operation in the gradual development of business, results in 45 903 800 passengers estimated, which divided by 521 200 population in area served results in 88.1 passengers estimated per capita. Then 45 903 800 passengers at five cents per passenger equals $2 295 200 total revenue, which divided by 521 200 population in area served equals $4.40 per capita.

The division of the $2 295 200 total revenue is as explained on a passenger mileage basis as shown by the passenger mileage percent columns, Statement 20:—

75.5 percent or $1 732 900 to North Broad street line.
4.9 percent or $ 112 500 to Market street line.
5.8 percent or $ 133 100 to other rapid transit lines.
13.8 percent or $ 316 700 to surface lines.

Operating Expenses—Unit Costs—In order to estimate accurately the operating expenses of the proposed rapid transit lines, a study was made of the costs in recent years of operation of subway and elevated lines in Philadelphia, New York, Brooklyn and Chicago. These costs of operation were compiled by years and reduced to a relative unit basis. From this study there were assumed for each of the new rapid transit lines unit costs of operation which, when applied to the service statistics, give the annual operating expenses.

Form of Operating Expense Estimates—The operating expenses for the recommended rapid transit lines were estimated and compiled as in Table XII.

TABLE XII—ESTIMATED OPERATING EXPENSES—PROPOSED NORTH BROAD STREET LINE, YEAR ENDING JUNE 30, 1919

Maintenance	Unit used in Estimate	Amount	Per Unit	Per Car mile
Track and roadway	Mile track	$111 400	$3 910	1.6c
Electric lines	Mile track	23 700	830	0.4c
Buildings	Car owned	16 400	100	0.2c
Cars and shops	Car owned	98 400	600	1.4c
Total maintenance	Gross earnings	$249 900	14.2%	3.6c
Transportation.				
Power	Kilowatt hour	$260 900	0.75c	3.7c
Trainmen	Car hour	150 200	30.0c	2.2c
Other operation cars	Car owned	90 200	$550.00	1.3c
Station expense	Station	112 500	$4 690.00	1.6c
Total transportation	Gross earnings	$613 800	35.0%	8.8c
Damages	Gross earnings	$ 26 300	1.5%	0.4c
General expenses	Gross earnings	52 600	3.0%	0.8c
Total operating expenses	Gross earnings	$942 600	53.7%	13.6c

Maintenance—Track and Roadway—A study of the cost of maintenance of track and roadway for several rapid transit lines shows the unit values given in Table XIII.

Maintenance—Electric Lines—Data on which the estimates for maintenance of electric lines were calculated are given in Table XIV.

TABLE XIII—UNIT COST FOR SEVERAL RAPID TRANSIT SYSTEMS.

	Brooklyn Union (Elevated)		Interborough (Elevated)		Interborough (Subway)		Philadelphia (Subway Elevated)	
	Cost per Mile of Track	Car miles per mile of Track	Cost per Mile of Track	Car miles per mile of Track	Cost per Mile of Track	Car miles per mile of Track	Cost per Mile of Track	Car miles per mile of Track
1908	$1 986	275 081	$5 034	547 032	$4 802	554 929	$1 138	143 747
1909	1 825	275 280	5 918	529 544	5 112	564 357	3 840	233 031
1910	2 332	302 196	4 872	538 295	6 587	613 660	4 730	290 656

From the data of Table XIII curves similar to those shown on Fig. 22 were developed and used in selecting unit costs of track and roadway maintenance for proposed rapid transit lines.

TABLE XIV—MAINTENANCE-ELECTRIC LINES.

System.	Cost per Mile of Track.				
	1908	1909	1910	1911	1912
Philadelphia (Subway-elevated)	....	$206	$334	$867	895
Interborough (Subway)	$1 058	996	621	...	...
Interborough (Elevated)	616	931	528	...	...
Brooklyn Union (Elevated)	496	450	422	...	...

TABLE XV—MAINTENANCE—BUILDINGS.

System.	Cost per Car Owned.			
	1908	1909	1910	1911
Philadelphia (Subway elevated)	...	$97	$156	$232
Interborough (Subway)	$93	125	87	
Interborough (Elevated)	79	86	85	
Brooklyn Union (Elevated)	63	96	68	

From Table XIV a unit cost of $1 000 and $500 per mile of track for maintenance of electric lines for subway and elevated, respectively, was selected.

Maintenance—Buildings—The figures of Table XV show the cost of maintenance of buildings for

several existing rapid transit systems. In the estimates of proposed rapid transit lines $100 per car owned was used as the unit cost for maintenance of buildings.

Maintenance—Cars and Shops—The data in Table XVI for various rapid transit systems was used as a basis for the unit cost per car owned in estimates of maintenance of cars and shops for proposed lines.

The diagram, Fig. 23, was constructed from the figures of Table XVI and was used in estimating unit costs for "Maintenance, Cars and Shops" item.

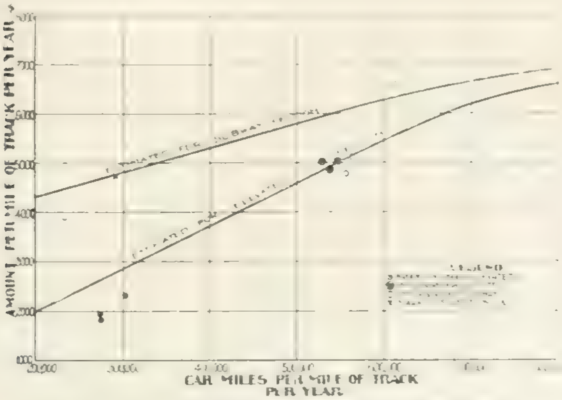

FIG. 22—MAINTENANCE, TRACK AND ROADWAY

Power was estimated at 0.75 cents per kilowatt-hour at the substation, which figure includes the estimated purchase price and substation expenses.

Trainmen's Wages were estimated at a uniform rate of 30 cents per hour.

Station Expenses—The unit cost used in estimating station expense for proposed rapid transit lines

FIG. 23—MAINTENANCE, CARS AND SHOPS

was $5 000 per station for first year of operation with $100 added each year thereafter. This estimate is based upon figures of Table XVII.

Expense Incident to Operation of Cars other than platform wages and power was based on the data of Table XVIII. Fig. 24 was constructed from the figures of this table and used in estimating unit costs for "Other Expenses of Operation of Cars."

Damages were figured at 1.5 percent of gross earnings. The ratio of damages to gross earnings for several rapid transit systems are given in Table XIX.

While the average of the percentages of Table XIX is lower than the percentage used, it is considered desirable to set aside 1.5 percent each year, and accumulate the balance at the end of the year in a reserve to offset the outstanding liabilities.

General Expenses—The ratio of general expenses to gross earnings for several rapid transit systems is given in Table XX. In the estimates of the proposed rapid transit lines general expenses were figured at three percent of gross earnings.

TABLE XVI—MAINTENANCE, CARS AND SHOPS

Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	25 770	$492	[illegible]	$373	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	375	29 645	450	[illegible]
1909	[illegible]	25 006	[illegible]	[illegible]	423	29 000	455	33 813
1910	238	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	417	35 030
1911	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	442	[illegible]

Year	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1909	502	30 803	449	39 296	830	56 161	507	38 794
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	514	42 581
1911							336	30 193
1912							426	37 112

TABLE XVII—STATION EXPENSES PER STATION

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	$3 597	[illegible]	[illegible]
[illegible]		6 350	6 400
[illegible]	[illegible]	5 [illegible]20	5 500

TABLE XVIII—EXPENSE OF CAR OPERATION [illegible]

Year	Philadelphia (Subway-Elevated)		Interborough [illegible]		[illegible]		[illegible]	
	Cost per Car Owned	Cars [illegible]	Cost per [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1908	$188	6.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1909	250	6.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1910	[illegible]	6.8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE XIX—RATIO OF DAMAGES TO GROSS EARNINGS—PERCENT

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

TABLE XX—RATIO OF GENERAL EXPENSES TO GROSS EARNINGS—PERCENT

[illegible]	[illegible]	[illegible]	[illegible]
Interborough (Subway)....	[illegible]	[illegible]	2.18
Interborough (Elevated)....	2.74	[illegible]	3.11
[illegible]	3.10	3.40	2.80

Other Revenue, (Statement No. 28)—The $1 732 - 900 passenger revenue is brought forward from passenger revenue statement 25, according to the division of revenue and the $22 400 advertising revenue

is calculated at \$250 per station ($24 \times \$250 = \$6\,000$) plus \$100 per car owned ($164 \times \$100 = \$16\,400$).

	\$1 732 000	Passenger revenue.
Adding	22 400	Advertising revenue.
	\$1 755 300	Total or gross revenue.
Deducting	942 600	Operating expenses (Statement No. 27).
	\$ 812 700	Net earnings for 1919, first year of operation.

Taxes The following rates were used in estimating taxes:—

0.5 of a cent per dollar on company securities
0.8 of a cent per dollar on gross earnings.
1.5 cents per dollar on realty and personalty.

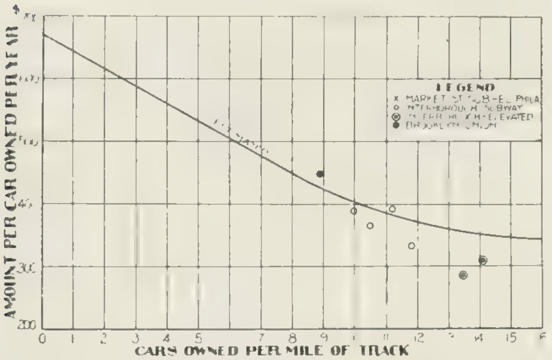

FIG. 24 EXPENSE OF OPERATION OF CARS OTHER THAN PLATFORM WAGES AND POWER

The principal for realty and personalty was estimated at \$3 000 per car owned (164 cars owned at \$3 000 per car) = \$492 000. The taxes for year to June 30, 1919, are given in Table XXI.

TABLE XXI—TAXES FOR YEAR TO JUNE 30, 1919.

Unit of Estimate	Principal	Rate (Cents)	Amount
Company's securities.......	\$6 352 600	0.5	\$31 700
Gross earnings............	1 755 300	0.8	14 000
Realty and personalty......	492 000	1.5	7 400
Total taxes for 1919.....			\$53 100

Contingency Reserve—It is considered necessary to set aside each year a contingency reserve to provide against abnormal operating expenses which may be expected to occur infrequently as a result of calamities, contingencies or industrial disturbances. This was estimated at \$28 300, or 3 percent of the \$942 600 operating expenses.

Renewal Reserve Charges on Structures—The estimate of renewal reserve charges is as follows:—

The total cost \$24 323 000 of subway structures to Erie avenue (including delivery loop) as shown in Statement 1, (page 146), is obtained by totaling sub-items (c) (d) (e) and (f) of Item 2 of Recommended Estimate "X" and total of Item 6, Recommended Estimate "I" in Statement No. 3, (page 148, Transit Commissioner's report). The annual charge, assuming the service value to be the same amount as the original cost with an estimated life of 100 years and allowing 3½ percent compound interest (equivalent to a rate of 0.116¢) is \$28 200.

The total cost, \$3 554 000, of branch elevated structures shown in Statement 1, page 146, is obtained by totaling subitems (a) and (b) of Item 2 of the recommended Estimate "X." Assuming the salvage value as 15 percent of the original cost, or \$533 100 gives the service value as the difference, or \$3 020 900. The annual charge on this amount with an estimated life of 75 years and allowing 3.5 percent compound interest (equivalent to a rate of 0.287 cents) is \$8 700.

The sum of the two, \$28 200 + \$8 700 = \$36 900 represents an investment by the city of \$27 877 000 (not including land).

Renewal Reserve Charges on Equipment—These were figured on an average life of 30 years with an allowance of 3.5 percent compound interest (equivalent to an annual rate of 1.94¢). On all four items (as shown in Table XXII) the principal was based on

TABLE XXII—SUMMARY OF ANNUAL CHARGES FOR RENEWAL RESERVE ON EQUIPMENT FOR YEAR TO JUNE 30, 1919

Rolling stock....................................	\$41 200
Feeders	2 500
Sub Stations	11 900
Car houses, yards, shops and offices..................	15 300
Total renewal reserve equipment.................	\$70 900

On an investment by the operating company of \$6 034 000

the value of the number of cars owned for different years:—

Cost of rolling stock based on 1919 cars (164 @ \$14 400 each) = \$2 362 000. Assuming the salvage value as 10 percent of the original cost, or \$236 200, gives the service value as the difference, or \$2 125 800. The annual charge on this amount at above rate is \$41 200.

Cost of feeders based on 1922 cars (265 @ \$1 200 each) = \$319 000. Assuming the salvage value as 60 percent of the original cost, or \$191 400, gives the service value as the difference, or \$127,600. The annual charge on this amount at above rate is \$11 900.

Cost of sub-stations based on 1922 cars (266 @ \$2 880 each) = \$766 000. Assuming the salvage value as 20 percent of the original cost, or \$153 200, gives the service value as the difference, or \$612 800. The annual charge on this amount at above rate is \$11 000.

Cost of Car houses, yards, shops and offices based on the 1924 cars plus one-third ($309 \times 1.333 = 412$ cars at \$2 400 each) = \$989 000. Assuming the salvage value as 20 percent of the original cost, or \$200 000, gives the service value as the difference or \$789 000. The annual charge on this amount at above rate is \$15 300.

STUDY OF FACILITIES IN LARGE AMERICAN CITIES

A series of maps was prepared for Philadelphia, New York, Boston and Chicago, to a scale of about one inch to the mile, and including the territory within a radius of 16 miles of the respective City Halls. This was called the "Metropolitan Area" and is shown for Philadelphia by Fig. 25.

United States geological survey sheets for Philadelphia, New York, Boston and Chicago, and their vicinities were mounted on cloth making a base map for each city slightly larger than 45 in. × 57 in. The scale of these maps is one inch to 62 500 inches, or approximately one mile per inch. For closer work in Philadelphia, Smith's map was used as a base. The scale of this map is one inch to 1 000 feet. Smith's map, however, does not extend farther west than the limits of Philadelphia county. It was therefore necessary to add to the west in order to have it co-extensive with the geological base map. The map was accordingly divided into three sections, each 42 in. × 54 in., and for convenience termed the northern, central and southern sections respectively. Three sections were added to the west, each 42 in. × 54 in., and termed the northwestern, west central and southwestern sections. The complete map was therefore 126 in. × 108 in. The data for the western sections were taken from Delaware and Montgomery county atlases and from maps at other scales. For the other cities the following maps were used as basic: Boston, Walker Lithographic Publishing Company's map, scale one inch to 1 920 feet; Brooklyn, August R. Ohman's map, scale one inch to 2 120 feet; Chicago, Rand McNally & Company's map, scale one inch to 2 112 feet, and smaller scale maps showing surrounding counties.

Due to the absence of the boundaries of many civil divisions on the U. S. Geological maps for Boston and vicinity, it was necessary to obtain this information from the report volumes of the Massachusetts Harbor and Land Commission.

Locating the City Hall of each of the respective cities and using it as a center, circles from two to 16 miles in radius, at intervals of one mile were described. The 5, 10 and 15 mile circles were distinguished from the others by heavier weight lines. The steam railroad

and electric railway lines were then brought out in relief. The steam railroad lines were colored in red and the stations indicated by short black cross lines. The stations were located by mileage, and all routes of lines verified from the various company data. The passenger lines only (no freight) were thus shown in relief, a solid line indicating a regular passenger line or lines, and a broken line indicating one used infrequently for passenger service—i. e., once or twice a day. The electric railway lines, both street and suburban, were shown by dark blue lines. The routes of some of these are shown on the geological map, but most of them had to be platted from company data.

Having decided that all metropolitan maps at this scale (one in. to 62 500 inches) were to be 34 in. x 42 in. the area enclosed by the 16th mile circle was centered within this size except in the case of Philadelphia (preference being given to territory in Pennsylvania over that in New Jersey), and of Chicago (Lake Michigan being to the east making it possible to include more of the territory to the west). The base maps were then complete, giving the following composite information:—

1—Territorial boundaries:—state, county, township, city and borough.
2—Passenger transportation lines:—steam railroad, and electric street and suburban lines.
3—Water areas:—rivers, creeks and lakes.

In order to avoid the confusion arising from the platting of a large variety of features on a single map, separate tracings were compiled for each of the following features of each of the above cities.

1—Civil Division Tracing.

This tracing gives the boundaries of water and civil divisions with their names. The civil divisions shown were state, county, township, city and borough.

The state line was made heaviest in weight, the county line not as heavy, and the township, city and borough lines lighter still. The shore or coast line was the lightest weight line used. The city halls of Philadelphia, New York, Boston and Chicago were indicated by a small cross. This is also the centre for the mile circles. Four corners were drawn to indicate the limits of the 34 in. × 42 in., and also to permit of the registering of the various tracings.

2—Steam Railroad Passenger Lines.

This tracing gives the passenger lines, with road names and stations and names. The railroads are indicated by heavy black lines with heavy or thin cross lines for stations. The heavy cross lines indicate regular stops for trains, while the thin lines are those of flag stops. The difference between regular and flag stops is further emphasized by using all capital letters for regular stops, and capital and small letters for flag stops. Ferry routes are indicated by fine, short dash lines. In order to obtain register with the civil division and other tracings, the four corners were indicated.

3—Electric Street and Suburban Lines. (Surface and rapid transit.)

The electric railway lines are shown by a lighter weight line than that used for the steam lines. Also the rapid transit lines, subway or elevated, were distinguished from the surface lines in that they are represented by a fine double line. The rapid transit lines were shown completely, while to avoid confusion the surface lines were not shown within the four mile circle. Where the tracks of the two railway companies are continuous, the division of ownership is shown by a cross-line and arrow pointed lines.

4—Combination Steam Railroad and Electric Railway Lines.

This tracing was made for Philadelphia only, giving the combined information of the steam railroad and electric railway tracings.

5—Population.

The population was platted for the metropolitan districts under consideration, from the bulletins of the United States Census. A convenient scale of one spot to 1 000 people was adopted. In platting these tracings the larger scale population maps (one spot to 100 people) were used as a reference.

6—Steam Railroad Passenger Fare and Time Zones.

The steam railroad fare tracings were platted directly over the base map. One was based on the commutation fare and the other on the excursion fare. One way rate only was platted, the data being taken from company tariffs. An example of the data furnished is given in Table XXIII.

[illegible] XX[illegible] PASSENGER [illegible]

Between Reading Terminal, Phila., and	[illegible]	[illegible] 60	[illegible]	[illegible]
Huntingdon street....	$3.60	6[illegible]	15c	[illegible]
[illegible]	[illegible]	6¾c	[illegible]	9c
Wayne Junction.....	4.35	7[illegible]	21c	[illegible]
Fischers	4.50	7[illegible]	[illegible]	[illegible]
W[illegible]	4.6[illegible]	7[illegible]	[illegible]	[illegible]

Fare zones at intervals of 10¢ were platted; when the fare one way was not an even figure as in the case of Wayne Junction by excursian rate, the fare zone desired was interpolated thus:

Wayne Junction.......	10½¢	Wayne Junction.......	10½¢
Nicetown	[illegible]¢	[illegible]	[illegible]
Difference	1½¢	Excess	[illegible]

[illegible] Excess [illegible]
1½¢ Difference [illegible]

The 10¢ zone will therefore be 1/3 of the distance between Wayne Junction and Nicetown *from Wayne Junction.*

The following commutation ticket rate was used to plat the fare zone maps of: Philadelphia, 60 trip; New York, 60 trip; Boston, 12 trip; Chicago, 60 or 54 trip.

The data for the steam railroad time zones were obtained from the various time tables. The time platted was that of the third fastest train, outbound. The time elapsed from the terminal to any particular station for every train was calculated and that of the third fastest used. In case there were only two different times, the slower train was used. The following calculations will serve to illustrate the method used. Time between Philadelphia (Market street ferries)—and Pennsgrove:—

Pennsgrove ...	[illegible] A. M.	[illegible]	[illegible] P. M.	[illegible]	[illegible]	[illegible]
Philadelphia .	7 [illegible]	[illegible]	1[illegible]	[illegible]	[illegible]	[illegible]
Elapsed Time	1 [illegible]	1:21	1 [illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]1	[illegible]	[illegible]	[illegible]	[illegible]

Arranged according to time elapsed, we have 79, 81, 88, 93, 94 and 97, from which we see that the 8:32 A.M.—88 minutes elapsed time—is the third fastest train. Pennsgrove would therefore be an 88 minute point. In order to obtain contours at 10 minute intervals beginning with the 10 minute contour, these points had to be found by interpolation as in the case of the steam fare.

7—Electric Railway Fare Zones, Fare Area and Time Zones.

a—The fare zones tracing was also platted directly over the base map. The data used were obtained from the various operating companies as far as possible. Information which was not obtainable in this way was taken from trolley guides for the various cities. The fare points as platted represent the most distant points which can be reached from City Hall for each unit fare of five cents and every additional five cent unit. The fare points also show the least expensive route to an objective point when there are two or more such routes. In the case of Philadelphia, a three cent ferry fare is included in the cost of reaching Jersey points. In Boston, the fare units vary from five to eight cents, so that the zones are not at every five cent interval.

For Philadelphia only a fare area map was made. This map assumes a walking area tributary to the suburban lines of three-fourths of a mile in width which is equivalent to 15 minutes at an assumed walking speed of three m. p. h.

b—The time zones map was platted from the running time between various points, from company schedules and also from trolley guides. The zones show the quickest way to reach any place on the various lines from the City Hall or the zone of origin. For Philadelphia, the zone of origin extended along Market street from Broad to Eighth streets, and on

Broad street from Arch to Walnut streets. The time, therefore, to any place is that from the nearest point on the origin to the place in question. For New York, the origin zone is represented by the area or part of Manhattan south of Forty-second street and bounded by the Hudson and East Rivers. In Boston, City Hall was taken as the origin, while in the case of Chicago, Union Loop bounded the origin zone.

The time zone map does not allow walking time excepting that necessary for changing cars, and is therefore a point-to-point zone map. The differentials allowed for these short walks and waits for cars in Philadelphia are as follows:

Location		Differential in Minutes
69th Street		3
Angora (Baltimore Avenue)		1.5
Darby (9th and Main)		1
Chestnut Hill (Pa. R. R.)		1
Chestnut Hill (City Line)		1
Wissahickon (Ridge Ave. and Sumac)		4
Willow Grove		1
Frankford		1
Media	For Chester via So. Pa. Traction Co.	3
	For Chester via P. R. T. Co.	1 and 3
	For Glen Riddle via So. Pa. Traction Co.	1
Chester	For Media via So. Pa. Traction Co.	5
	For Media via P. R. T. Co.	1.5 and 1.5
Collingdale	For Media	10
	For Chester	10
At Parker and Balto. Ave. for Media		7.5
Norristown	For Pottstown or Lansdale	8
	For Swedeland	5
	For Conshohocken	8
	For Chestnut Hill	8
Trooper	For Skippack	5
Poquessing Creek	For Doylestown	3
Bristol	For Doylestown	5
Camden	Market St. Ferries	16
	Chestnut St. Ferries	22

The zones for Philadelphia, New York and Boston are the result of rapid transit and surface riding, while those for Chicago are only for rapid transit riding.

8—Rapid Transit Systems.

The rapid transit system tracings show both the present lines and those either under construction or proposed. The present routes are shown by solid lines, and the proposed routes by dash lines. The systems were first platted on the larger scale maps and later to the geological scale.

Check on Work—The information as finally worked up was checked not only several times by different men, but was also sent for verification to the cities whose statistics have been used.

The Philadelphia information, except in one or two minor cases, was supplied by the various companies on request. This information included data as to routes, rates of fare, running times, operating schedules, etc. The platting was done by different men and was checked several times.

CENTER OF POPULATION OR MEDIAN POPULATION POINT OF PHILADELPHIA

In finding the median population point of Philadelphia, a copy of the spot map with traffic sections, on a scale of one-half mile to the inch, was used. On this map the population in each such section was noted. The population figures used were those of the 1910 census report, revised to July 1, 1912, so that the Median Point is located as of July 1st, 1912.

The locating of the Median Point was divided into two operations:—

1—Platting the north and south line which would divide the population equally.

2—Platting the east and west line which would divide the population equally.

The intersection of these two lines is the median population point.

The north and south dividing line was assumed to fall within the column of traffic squares centered on Broad Street and bounded by Eighth Street on the east and Twentieth Street on the west. (See Fig. 5.) Totals were then made of the population in the traffic squares east of this column, in those west of the column and of those in the column itself.

Total population in traffic squares east of column...	588 700
Total population in traffic squares west of column...	625 500
Total population in traffic squares in the column....	409 000
Total..	1 623 200

From these figures it can be seen that the line would fall within the column. As there were 409 000 population inside the column, the north and south median line should be one which divided this 409 000 so as to place 222 900 east and 186 100 west of the line. To locate this line, the column was subdivided into strips parallel to the line, the spots counted in each strip and new approximate locations calculated, each closer to the true one, until the line was finally located in Fifteenth Street.

By a similar process, the east and west line was found to lie slightly above Mt. Vernon Street. Therefore, the location of the median population point would be approximately Fifteenth and Mt. Vernon Streets.

CENTER OF GRAVITY OF POPULATION OF PHILADELPHIA

To find this, a copy of the spot map on a scale of one-half mile to the inch was used. On this map the city was subdivided into 122 traffic squares or fractions of squares and the population in each such division noted. The population figures used were those of the 1910 census report revised to July 1, 1912, so that the center of gravity is of date July 1, 1912.

The center of gravity was obtained as follows:—

x = distance above east and west base line.
y = distance east of north and south base line.
n = summation of moments to the north of east and west base line.
s = summation of moments to the south of east and west base line.
e = summation of moments to the east of north and south base line.
w = summation of moments to the west of north and south base line.
p = total population.

Then $x = (n - s) \div p$ and $y = (e - w) \div p$

The east and west base line was assumed along Callowhill Street, and the north and south base line along Twentieth Street.

The moments of the population in each traffic section or the population in each traffic section (considered acting from its center of gravity), multiplied by its distance from each axis, were then computed and listed as in Table XXIV.

TABLE XXIV—MOMENTS OF POPULATION BY DISTRICTS.

Section	Population	Horizontal Axis: Distance in Miles	Horizontal Axis: + Moments	Horizontal Axis: — Moments	Vertical Axis: Distance in Miles	Vertical Axis: + Moments	Vertical Axis: — Moments
18	56 700	0.5	28 350		0.5	28 350	
21	54 100	1.5	81 150		0.5	27 050	
26	46 200	2.5	115 500		0.5	23 100	
16	19 900	—0.5		9 950	—0.5		9 950

The moment columns were totaled and entered in the formulae and the ordinates of the center of gravity computed.

Distance above east and west base line	=0.866 miles
Distance east of north and south base line	= 0.242 miles

Upon platting these ordinates the center of gravity was found to fall approximately 150 feet west of Eighteenth St. and 300 feet north of Girard Ave., or approximately at Eighteenth St. and Girard Ave.

Efficiency of Railway Sub-Stations

L. P. Crecelius
Superintendent of Power,
The Cleveland Railway Company

THE EFFICIENCY of the electrical apparatus used in railway sub-stations is usually fairly high as determined by test reports secured while the machinery is operating upon the test floor of the manufacturer, but when placed in operation upon a railway system it is surprising to note how far below the mark the overall efficiency of the sub-station frequently falls. It is not uncommon to find that the conversion losses run as heavy as 25 percent. It is therefore extremely important that sub-station apparatus should be properly proportioned and carefully operated so as to show a close agreement between theoretical and actual efficiency over a prolonged period, and this condition is possible of attainment if sufficient care is exercised. As an example, detail figures of the efficiency of the apparatus both as found by test and in regular operation in the sub-station of The Cleveland Railway Company are included below. The apparatus comprising this equipment was carefully designed from the standpoints of ruggedness and economy.*

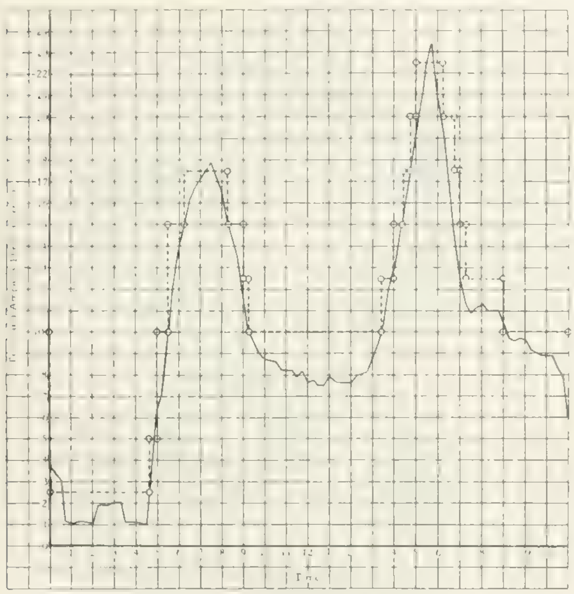

FIG. 1—LOAD CURVE OF CLEVELAND RAILWAY COMPANY

The full line indicates the actual load of the station and the dotted lines the capacity of the apparatus in operation.

The power input to the four sub-stations for the month of July, 1914, was 4 518 610 kw-hrs. alternating current, whereas the power output as measured at the direct-current bus-bars for the same period was 4 154 120 kw-hrs. The conversion loss therefore is 364 490 kw-hrs., which is 8.07 percent of the power input.

*For details of this equipment see a paper by the writer in the Proceedings of the American Institute of Electrical Engineers for March, 1914.

Due to the necessity of getting machines on the line before the load has increased, and of leaving them on until after the load has decreased, it is practically impossible to operate the equipment on a system having peak loads so as to average better than full load per machine. Therefore, according to the test data given in Tables I and II, the lowest possible resulting losses in the stations on this basis would be:—

Transformers	1.3% of 4 518 610 kw-hrs.	=	58 742 kw-hrs.
Blowers	0.5% of 4 459 868 kw-hrs.	=	22 299 kw-hrs.
Converters	5.0% of 4 437 569 kw-hrs.	=	221 878 kw-hrs.
Cables, leads, etc.	0.4% of 4 215 691 kw-hrs.	=	16 862 kw-hrs.

Total loss .... 319 781 kw-hrs.

Ratio 319 781 ÷ 4 518 610 = 0.07075 or 7.075 percent.

The difference therefore between the theoretical and actual loss of power in these stations is 8.07 — 7.075 = 0.995 percent, to which must be charged such unavoidable losses as the starting of the machines and the difficulty of getting the station operators to exercise the utmost care in getting the apparatus on and off the line promptly.

TABLE I—EFFICIENCY OF 1500 KW, 60 CYCLE, 600 VOLT ROTARY CONVERTERS

Percent Full Load	Percent Efficiency
50	91.8
75	94.0
100	95.0
125	95.5
150	95.6

TABLE II—EFFICIENCY OF 60 CYCLE, 11 000 VOLT SINGLE-PHASE TRANSFORMERS

Percent Full Load	Percent Efficiency
50	98.4
75	98.8
100	98.7
125	98.6

The most important factor contributing to high sub-station efficiency is obviously the use of economical equipment. The stations above discussed therefore have an advantage in this respect because of the fact that rotary converters are used in place of motor-generator sets. In addition the design of the equipment included excess active materials above that used in standard equipment.

Second in importance is the matter of the size of the units; unless the capacity of the units be kept to a point which permits of flexibility in getting the machines in and out of the circuit to follow load changes closely it is quite obvious that most of the advantages of highly efficient equipment are lost.

Third in importance is good operation. By this is meant careful attention to maintaining the apparatus at all times in first-class condition, and the drill-

ing of the operators to exercise the utmost vigilance in regard to loading. For this purpose it has been found profitable to have the station operators draw the load diagram illustrated in Fig. 1, containing in dotted lines the capacity of units in the circuit at any time with reference to the load. The operators are carefully instructed in the preparation of these curves and in their significance. On the reverse side of the load diagrams are blanks for hourly readings of the watt-hour meters which register the input to the station from each feeder, and the output from each converter to the direct-current bus-bars, with a summary in the form of total kilowatt-hours per hour and per day. The operators are obliged to fill in these blanks, the object being to keep them continually occupied with such details in order to hold their attention to the switchboard.

That such details as discussed in the case above are important and justifiable may be better understood perhaps by the explanation that a difference of one percent in efficiency is worth $3 800 per annum in the amount of power involved.

Recent Developments in Railway Motor Gearing

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AMONG the new problems which came up with the introduction of electric railway service was the development of efficient motor gears and pinions. The materials available for the manufacture of these gears and pinions were cast and malleable iron for the gears, raw-hide and machinery steel for the pinions. At first, about an equal number of raw-hide and steel pinions was used, most of the gearing being of the cast iron grade. It soon developed that the raw-hide pinion, while tending toward quiet operation, was not so economical as the machinery steel pinion, with the result that the raw-hide was quickly eliminated. Malleable iron gearing with the toughness characteristic of malleable iron was found to be more economical than ordinary cast iron gearing, but it was not long before the gear manufacturers, in their investigation and research, found that a cast steel gear was practical, which being harder and of greater strength, produced more mileage than either a cast iron or malleable iron material.

About twelve years ago, the most progressive gear manufacturers made experiments along the lines of the tempering of machinery steel pinions with a view toward increasing their strength and life. The early experiments in this tempering were made without any changes in the analysis of the steel used, and were very crude as compared with the present day methods, but were a decided improvement over the untempered material. In the making of the early cast steel gears, little attention was paid to the designing of a gear that would lend itself to economical manufacture from the standpoint of ease in molding and casting, with the result that perhaps 20 to 30 percent of all the cast steel blanks, from which gears were manufactured, were rejected on account of blow-holes, and a great many gears failed in service due to undetected blow-holes as well as inherent defects such as internal strains which were set up in casting due to the shrinkage effect. The next step in the development of cast steel gearing, therefore, was along the line of changing the designs to meet the conditions.

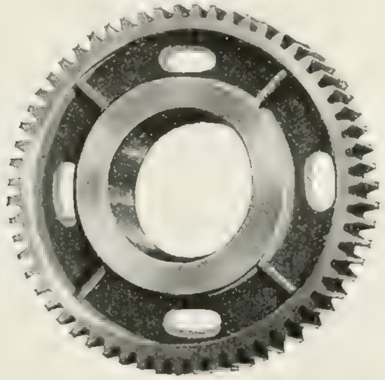


FIG. 1—AN EXAMPLE OF OLD-STYLE GEAR

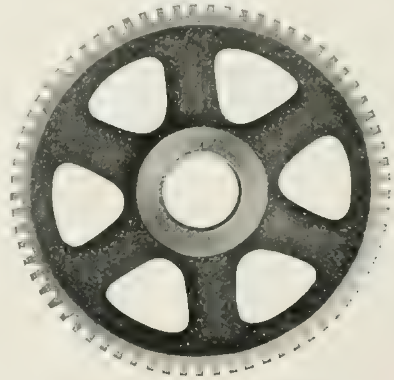


FIG. 2—NEW SIX-SPOKE GEAR

In casting a steel gear, its contour should be such as to eliminate sharp angles and abrupt changes in thickness of section in order that the inherent defects above referred to can be minimized. In Fig. 1 is shown one of the old style cast steel gears which was very heavy and which was very poorly adapted to efficient as well as economical manufacture, compared with the more modern design of cast steel gearing shown in Fig. 2. The difference between these designs lies largely in the fact that in the more modern

type, which is a six-spoke style, such shrinkage holes as may exist will be located safely below the base of the teeth. This is due to the fact that these holes will generally come at the center of gravity of each section, which in the old style design, frequently resulted in these defects occurring at or above the base of the teeth, thereby reducing their strength very materially. In the more modern design, all corners have generous fillets and there are no abrupt changes in direction or section, the shape and area of the spokes permitting rapid and uniform flow of the metal while casting, thus making it possible to produce solid and uniform metal throughout the gear.

While this more modern design of cast steel gearing is stronger and more efficient, as well as 5 to 10 percent lighter than the old style, great need for even a more efficient and economical material has developed through the increase in the severity of present day operating service. By that is meant the increase in the schedule, as well as weight of cars, which in turn necessitate increase in the size and horse-power of motors. These changes tend to require more space for the larger and more powerful motors, thereby restricting the available space for the gear.

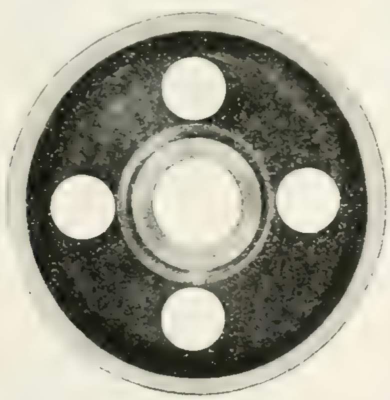


FIG. 3—FORGED GEAR BLANK

The manufacturers of forged and rolled steel wheels, being convinced by the gear makers of the necessity for a better material for motor gearing, developed what is known as the forged steel gear blank made in very much the same manner as steel wheels. The gear manufacturers obtain these forged or rolled blanks in the same shape as they previously obtained the cast steel blanks, machining and cutting this material in very much the same way. The blank and the finished gear are shown in Figs. 3 and 4. The forged or rolled steel gear overcomes such inherent defects as were found in cast steel gears, the blank being made from a high grade hearth steel and pressed or rolled into the required form at a red heat in special machines designed for this work.

The first forged steel gears put in service very soon showed that previous failures due to the inherent defects found in the cast steel gear were minimized and also brought out the fact that considerably increased life could be obtained from the forged steel material over the cast steel, this increase ranging from 20 to 40 percent. As the forged steel gear could not be made economically in the split style, it was necessary for the operator who wished to gain the advantages inherent in the forged gear to use the solid gear, with the result that, at the present time, most of the large railway properties are now operating with solid style gearing. Further developments, through which the life of the forged gear has been still more increased, have weakened the argument for the use of split gears. By that is meant that the life of the higher grades of forged gearing (which will be discussed later) is such as to minimize the necessity of removing the gears. The only advantage of the split gear over the solid gear is the ease of installation and renewal, and the long lifed solid gear entirely offsets this advantage, except for the small operator whose shop equipment cannot handle solid gears.

All of these changes effected through investigation and research led the operator to observe the results which he was obtaining from the respective qualities of the gearing and to realize the importance of close coöperation with the manufacturers who in turn were continually working to produce a gear and pinion which would give greater life with no breakage.

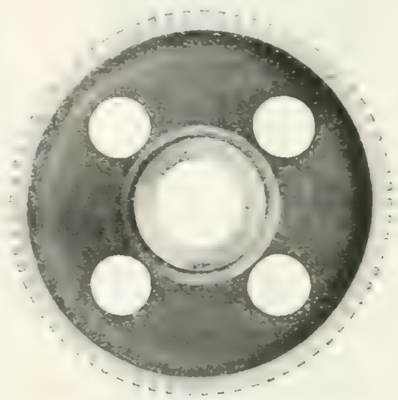


FIG. 4—FINISHED FORGED GEAR

About the time it was determined that the forged steel gear would eliminate such of the previous breakages as were due to defective castings, the manufacturer began his experiments with the heat treatment or tempering of this material. Through his original experiments in the heat treatment of pinions, he learned that heat treatment was not a simple operation, but brought into the manufacture of motor gearing variables which made the problem very complicated. It was found that for any given service the life of the gear or pinion was largely dependent upon the hardness of the material on the wearing surface, as well as the strength and toughness. The more deeply the investigation into the heat treatment, the stronger was the realization that the first step in the manufacture of high grade gearing was the proper selection of material from the standpoint of chemical analysis, and the present progress of motor gearing is largely controlled by this selection of materials and the appropriate heat treatment of same.

The first experiments in heat treatment were with the oil tempering of machinery steel pinions, and it was natural that continued experiments should be along the lines of oil tempering. The machinery steel from which the original pinions were manufactured was of medium carbon and it was thought, by the use of the higher carbon and oil tempering, that a very much harder wearing surface combined with strength and ductility could be obtained. While some of the initial product developed some troubles, the ultimate result was the production of gears and pinions having considerably more life than the untreated stock or the oil-tempered medium carbon steel.

Through the heat treatment of gearing was brought out the fact that hardness of the surface was largely dependent upon the amount of carbon in the steel and the various gear manufacturers through their investigation found that a gear could be produced with a high carbon surface and a low carbon core or center, which was termed "Case Hardened Gearing." The case hardening of steel has been known for a great many years, and the gear and pinion manufacturers therefore followed along the lines practiced by other industries in the past. Case hardening comprises two distinct operations; namely, carbonizing and heat treatment. The gear or pinion to be carbonized is machined from a low carbon blank and is packed in an air tight box with some carbonaceous material, such as charcoal, bone dust, etc., and heated in the furnace to a temperature ranging from 1 600 to 2 000 degrees F., depending upon the carbonizer used. The steel, having great affinity for carbon, absorbs carbon from the carbonaceous material and the carbon content of the surface is increased from low carbon to high carbon. The longer this operation is carried on, the greater this carbon penetration. For example, if this operation is carried on for 12 hours, the depth of carbonizing may be approximately 1/16 inch, depending upon the carbonizer used and the temperature at which the operation is carried on, while if the operation extends over 24 hours, its depth of carbonizing may be approximately ⅛ inch. The resultant product after carbonizing is a gear or pinion with the high carbon surface and the low carbon center or core which can, through proper heat treatment, be made very hard on the surface and very tough in the center.

The manufacture of case hardened gearing is of necessity very costly and its introduction was, therefore, very slow until the operator found that by the use of this higher priced material he could obtain from three to five times the life of the untreated stock. In a great many cases this material proved so satisfactory that changes were made from the untreated gearing to case hardened gearing without any consideration or trial of intermediate grades. The gear manufacturer, finding that the operator could be prevailed upon to buy the higher grade of gear, spent a great deal of time and money in the development of this grade of material to its highest possible efficiency. This development and investigation brought out the fact that not only was the life of gearing dependent upon its surface hardness and strength, but also that the refinement and density of the structure of the steel had a considerable bearing on the results produced. It was found that this refinement of structure, as well as

FIG. 5—CASE HARDENED GEAR TOOTH, SHOWING DEPTH OF CASE AND CORE

FIG. 6—EXAMPLE OF PROPER HEAT TREATMENT OF CARBONIZED TOOTH

FIG. 7—EXAMPLE OF IMPROPER HEAT TREATMENT OF CARBONIZED TOOTH

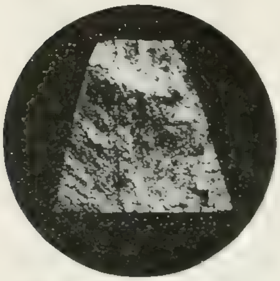


FIG. 8—OIL TEMPERED—PRESENT PRODUCT

FIG. 9—CASE HARDENED—PRESENT PRODUCT

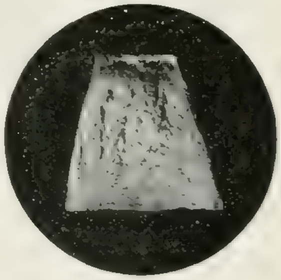


FIG. 10—"BP" GRADE—PRESENT PRODUCT

hardness and strength, could be controlled through heat treatment and that the most efficient material could only be produced through a very accurate and uniform heat treatment. The variations in hardness, as well as strength and refinement of structure through heat treatment, can be understood from the photographs shown in Figs. 5, 6 and 7. The carbonizing may take 24 hours and even 30 hours, while the heat treatment of the carbonized gearing may necessitate heating and quenching two or three times.

While case hardened gearing will undoubtedly give greater mileage than other grades, its cost makes this grade uneconomical for the majority of services. For example, the application of the case hardened gear in service where the life will be 10 or 15 years, makes the ultimate cost of this gear extremely high when the interest on the investment is considered. The gear manufacturer has done everything possible to lower the cost of the producing of this grade of material, but there are limitations to which cost cutting can be carried owing to the fact that, unless the carbonizing and the heat treatment is properly done, the case hardened gear is unsafe and unreliable, as a slight variation in the temperatures at which the operations are carried on may produce either a brittle gear which will break in service, or a soft gear which will develop poor mileage.

TABLE I—PHYSICAL CHARACTERISTICS OF VARIOUS GRADES OF GEARS

Grade	Relative: Life	Relative: Cost	Relative: Hardness	Average physical properties: Surface Hardness	Tensile Strength	Elastic Limit	Elongation Percent	Reduction Area Percent
Untreated cast steel	1.00	1.00	1.00	146	70 000	[illegible]	22	[illegible]
Untreated forged steel	1.25	1.05	1.08	[illegible]	[illegible]	40 000	22	[illegible]
Oil tempered forged steel, early product	2.60	1.30	1.75	262	100 000	[illegible]	17	[illegible]
Oil tempered forged steel, present product	[illegible]	1.35	2.25	340	[illegible]	[illegible]	12	[illegible]
Case hardened early product	4.00	1.80	[illegible]	555	Impractical to obtain test.			
Case hardened present product	[illegible]	[illegible]	4.00	[illegible]	Impractical to obtain test			
BP grade	[illegible]	1.45	[illegible]	[illegible]	139 000	[illegible]	15	[illegible]

[illegible]

While the case hardened gearing was found to be more economical than the majority of oil tempered gears, operators were continually bringing out the fact that its high cost made the ultimate economy of its use questionable, and the manufacturer, therefore, began making experiments toward the development of a material better than the oil tempered stock which could be produced for less money than through case hardening. Through the help secured from the operating man in the matter of testing out of different experimental grades, the company with which the writer is connected was finally able to develop a grade of gearing which has every indication of satisfying the needs of the railway service of to-day. This material is produced by the heating of a gear or pinion in a special furnace designed for this work and then quenching in such solutions as will produce a material having a surface hardness which is practically the same as case hardened gearing, but the cost of production of which is very much less. This is known as the "BP" grade and, from all tests so far conducted, it seems to be not only a more economical material, but a safer grade of gearing than even the oil tempered or the case hardened stock. The most noticeable feature of this grade is the fact that, while it has practically the same surface hardness as the case hardened grade, this hardness gradually tapers off toward the center of the teeth, resulting in a very strong and tough material, there being no abrupt change between the hardness of the surface and the hardness of the center.

There are very few places wherein this material will not give the life necessary for the most efficient operation. A comparison between the structures of the different materials is shown in Figs. 8, 9 and 10, and in Table I a comparison of the physical properties of the different grades.

TABLE II—COST COMPARISON BETWEEN VARIOUS GRADES OF GEARS

Items	Cast steel	B. P. grade	Case hardened
Initial cost	$12.50	[illegible]	[illegible]
Compound Interest at 6% [illegible] yr	2.70		
[illegible] yr		17.8[illegible]	
[illegible] yr			41.20
Cost of installing	1.00	[illegible]	1.00
Total cost	16.20	36.95	67.20
Life of gear in miles	[illegible]	[illegible]	[illegible]
Years life at [illegible] miles per yr	[illegible]	[illegible]	[illegible]
Cost per 1 000 miles	[illegible]	[illegible]	[illegible]

Table II is given as a means of indicating how to make a comparison between the different grades. It takes into account the average cost of gearing of the respective grades and an estimated life calculated from Table I. As the average mileage in normal city service is about 30 000 miles a year and the life of the standard cast steel gear about 100 000 miles in the average normal city service, the calculation is based on this assumption.

The above analysis indicates the economic advantage of using the newer gears. There are also other factors to be considered, such as the relation of the life of gear to that of the axle, motor and other parts of the equipment whose life cannot be calculated so closely as gearing. A gear with a considerably greater normal life than surrounding parts would, of course, not be desirable and the life of the newer gears seems to be nearer an average than the case hardened gears.

The Waterloo, Cedar Falls & Northern Railway

W. G. Brooks
Chicago Office,
Westinghouse Electric & Mfg. Company

THE WATERLOO, Cedar Falls & Northern Railway Company, known as the "Cedar Valley Road," operates a system of electric railway lines through the Cedar River valley from Waverly on the north to Cedar Rapids on the south. The country served is a rich agricultural community ranking with the best in Iowa. The cities connected are prosperous manufacturing centers.

Waterloo, which is the hub of the system, is a progressive city of 35 000 population, having over one hundred factories. In this city the company operates a freight belt line which connects the majority of the factories with its own interurban lines and with the steam railroads. The Waterloo local street car service is also operated by this company, the local lines radiating from the business centers to the factory districts, suburbs and parks.

Cedar Falls, a city of 10 000 people ten miles west of Waterloo, is the terminus of the first interurban line built by the Cedar Valley Road, which has been in operation about twenty years. The railway company operates local service on a loop connecting the business section with the Iowa State Teachers' College, all interurban and local cars passing a terminal depot located in the center of the business district. A separate freight depot, where car load freight is taken care of, is located close to the business section. Forty-eight passenger trains and four freight trains are operated daily between Waterloo and Cedar Falls.

Waverly, 22 miles from Waterloo, the terminal of the northern division, is also a factory city of about 6 000 people. This line serves the towns of Denver and Glasgow, which are trading centers for prosperous farmers. Intermediate sidings are provided where car load freight is unloaded by the farmers and where grain and stock is loaded.

Sixty miles of line has just been completed south of Waterloo, connecting Waterloo with Cedar Rapids, a city of about 50 000 population. This line has been in operation as far as Center Point since last spring. The territory served is a fertile agricultural district, and several medium sized cities have been connected to Waterloo and Cedar Rapids by the opening of this line. The new line is located on a 100 foot private right-of-way with a maximum grade of one percent and a maximum curve of six degrees on the main line, 85 pound steel rails being supported on cedar ties and ballasted with gravel. Each of the main stations has a 2 000 foot passing track with industrial tracks leading from it. Stock yards, and in most cases coal and lumber yards, are provided near the stations, and one or two grain elevators have been erected. All depot buildings are built of brick and roofed with asbestos shingles. Where sub-stations are located the sub-station and depot building are all in one.

The Cedar Valley road was the pioneer company to compel steam roads to interchange freight with interurban roads. As a result, 70 percent of the switching from the steam roads in Waterloo at the present time is performed by the Cedar Valley road, since the larger factories are located on their belt line around Waterloo. The same service will be rendered in Cedar Rapids, but the belt company there will be the Cedar Rapids Terminal & Transfer Company, which will receive freight from the Waterloo, Cedar Falls & Northern road and from all the steam and interurban roads coming into Cedar Rapids, and will distribute this freight and do all switching wherever possible. This freight transfer will allow several roads entering Cedar Rapids to enjoy the business of a northern territory from which they have been unable to receive freight heretofore. In other words this 60 miles forms a connecting link and a feeder to the steam roads in Cedar Rapids.

This company not only handles car load freight, but has also inaugurated a unique system of collecting freight in less than car load quantities. As practically all of the large manufacturing interests in Waterloo are located along their line, the company has a flat car equipped with motors, which calls at certain definite periods to secure the smaller freight shipments, which are conveyed to the freight house of the company for shipment. This company is thus providing to the manufacturing interests of Waterloo one of the highest class and most efficient services that can be provided in both carload and less than carload shipments.

Until the present time the entire system has been operated with a trolley voltage of 650 volts, the sub-stations being spaced from six to ten miles apart. When the new line from Waterloo to Cedar Rapids had progressed part way, the freight and passenger business had grown to such an extent that it was found advisable to change the trolley voltage to 1 200 volts and to space the sub-stations from 16 to 17 miles apart. This arrangement will give better average trolley voltage, higher sub-station load factors and lower operating costs in labor and maintenance. The new 1 200 volt sub-stations will be located at Gilbertville, Brandon, Center Point and Cedar Rapids Yards, replacing the 650 volt stations at Gilbertville, La Porte City, Brandon, Urbana and the Center Point, and the proposed stations at Lafayette, Louisa and Cedar Rapids Yards. Sub-stations operating at 650 volts are located on the old lines at Cedar Falls, Glasgow, Denver and Mills. Four rotary converters are lo-

cated at the power house in West Waterloo and two are now being installed at the company shops in East Waterloo.

On the line between Cedar Rapids and Waterloo, which will very shortly be converted to 1 200 volts, a high-speed, limited passenger service will be rendered by four combination passenger and baggage cars and three standard parlor cars. The cars for this service weigh 90 000 pounds each and will be equipped with four 120 horse-power Westinghouse motors. The parlor cars resemble those of the steam road in every detail with the exception that they are equipped with motors and will run in train with a combination passenger car. The time for 60 miles between Waterloo and Cedar Rapids will be one hour and 45 minutes. The local passenger service between these cities will be performed with 35 ton motor cars equipped with four 100 horse-power Westinghouse motors and pulling a 20 ton trailer. These cars will make the run in approximately two and one-half hours, making all stops. The freight service will be performed by five 60 ton locomotives equipped with four 250 horse-power

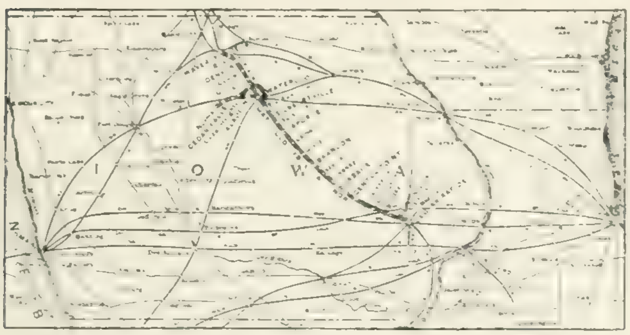


FIG. 1—MAP OF CEDAR VALLEY ROAD

Westinghouse motors, which will make the run between Waterloo and Cedar Rapids in three hours. The capacity of these locomotives is 800 tons of freight at 24 miles per hour. Westinghouse unit switch control will be employed on all of this equipment. The traffic on the south line is very heavy at the present time and is expected to reach the limit of its equipment very shortly.

The power house and all the sub-station buildings are fire proof. Three-phase, 25 cycle current is generated at 2 300 volts and is stepped up to 44 000 volts for transmission. The power house building has floor room for four turbines of a total rated capacity of 12 000 kilowatts; two 1 500 kw, 1 500 r.p.m. machines being now in operation. A 50 kw, 120 volt commutating-pole exciter is direct-connected to each turbine and an engine-driven exciter is used as an auxiliary. The switchboard consists of 27 panels, including blank panels for future apparatus. Two sets of three 500 k.v.a. step-up transformers are now in service with floor space provided for two more sets. All high-tension outgoing oil switches are remote control solenoid-operated. The low-tension wiring is placed in conduit and the high tension is carried on pin-type insulators mounted on pipe frame-work. Both the direct and alternating-current circuits are protected with electrolytic lightning arresters, the high-tension arresters being installed out doors.

In the boiler room three 500 horse-power boilers equipped with superheaters, chain grate stokers, economizers and induced draft provide steam at 200 pounds pressure and 100 degrees superheat; each boiler being a separate unit. All the auxiliary apparatus in the boiler room is motor driven. Iowa coal, which is low in B.t.u. and high in ash content, is dumped into a track hopper from the cars and conveyed by means of industrial cars to an elevator where it is elevated to the bunkers in front of each boiler. The ash is conveyed in a similar manner from the ash pits to a hopper over the coal supply track. The condensers are of the jet type, taking water from Black Hawk Creek, which flows near the power house. The condenser pumps are turbine driven.

The standard sub-station building is 22 by 40 feet with an 18 foot ceiling. The 650 volt stations have one 44 000 volt oil switch with overload relays; three 165 k.v.a. step down transformers and a 500 kw, 500 r.p.m. non-interpole rotary converter. The switchboard consists of four panels, one each for the direct and alternating-current sides of the converter and two feeder panels. The 1 200 volt sub-stations will consist of a high-tension oil switch, three 185 k.v.a. air-cooled transformers and a 600 kw, 750 r.p.m., 1 300 volt commutating-pole rotary converter which will commutate 200 percent full-load current momentarily. The switchboard will consist of one oil-switch panel and one starting panel on the alternating-current side, and one converter and two feeder panels on the direct-current side, each panel being in three sections. The knife switches and direct-current circuit breakers are hand operated and remote controlled and are mounted on the front of the board; the ammeters are provided with a grounded case to protect the operator. All the converters in both 600 and 1 200 volt sub-stations are self-starting, and electrolytic lightning arresters are provided on both direct and alternating-current lines.

All overhead lines with the exception of the one between Waterloo and Cedar Rapids are standard direct-suspension construction; in general a 4/0 trolley and a 4/0 feeder are being used. The line from Waterloo to Cedar Rapids is of the five point catenary construction with 150 foot pole spacing on tangent track, the poles being of Idaho cedar, 40 feet long. The overhead construction is insulated for 1 500 volts, porcelain insulators being generally used. The high tension line is spaced in delta with 52 inches between wires and is sectionalized at each sub-station with Burke horn-gap switches.

Tripling the Capacity of the Italian Giovi Line by Electrification

L. Pontecorvo
Societa Italiana Westinghouse

BY FAR the most important of all economic reasons which determine the electrification of a steam line is the necessity for increasing its capacity, once the line is congested by too heavy traffic. In such a case electric traction greatly helps the railway service. The actual results of electrification brought about by such conditions are, however, quite unknown as nothing has heretofore been published in connection with such cases. With the exception of the Norfolk & Western in the United States, an examination of all trunk lines with heavy freight and passenger service shows no case where electrification was determined by the necessity of increasing the capacity of the line. In all cases the determining factor was due to other causes. The electrification of the Italian State Railways, however, was brought about for that and for no other reason.

ALL the three-phase installations of the Italian State Railway (with the exception of the Valtellina lines electrified twelve years ago for experimental purposes) were determined by the necessity for increasing the capacity of the lines, the Italian State Railway having found the three-phase system the most suitable for increasing the capacity of trunk lines with very heavy grades. The actual results obtained are given in the following pages on a line presenting the most difficult service conditions; and where the steam service had exhausted all its resources and could not be improved upon, the line being operated at or near the saturation point. The line referred to is the Giovi line in Italy, running from Genoa to Ronco, which can be considered as completely regenerated by three-phase traction, having acquired as regards the freight service, which is the most important, the same capacity, if not greater, than the parallel line, the so called "Subsidiary Line," which has grades only half as steep as the older lines, and has the most up-to-date block signal system. It will contribute to a better understanding of these results to describe briefly the electric railway system in Italy and its developments, especially as regards the Giovi line, which is one of the oldest railway trunk lines in Italy.

L. PONTECORVO

ITALIAN ELECTRIC RAILWAY SYSTEM

The Italian State Railway has a large number of electric railway lines which are situated in the most industrial part of Italy, as shown in Fig. 2. Table I gives their most important characteristics. Of all these lines, the first one only, the Milan-Varese, is a direct-current line at 600 volts and the electric service is limited to passenger trains. All the others are three-phase, 3 000 to 3 300 volts, 15 to 16.6 cycles with electric service both for passenger and freight trains. The rest of these railway lines, all equipped with the same system of traction and operated by the same type of locomotives, constitute the most complete and best organized example of electrification in Europe.

The Valtellina line, running from Lecco to Sondrio and Chiavenna, was electrified in 1902 for experimental purposes. However, it has derived a great many advantages by its electrification outside of the fact that the electric service has shown itself more economical than the steam service. In 1897 the operating expenses per axle (with steam service) was Lire-0.129 per km. (4.15 cents per mile), and in 1902-3 (with electric service), L-0.114 per km. (3.67 cents per mile); that is, a reduction of 12 percent, including all interest and depreciation on the investment.

Of the other lines, the old Giovi line (double track) was electrified in 1910 to increase its capacity, and so were the Bussoleno-Modane line (partly single and partly double) in 1912-1914, and the Savona-San Giuseppe (single track). The electrification of the Monza-Lecco line was due to various reasons, chiefly the advantage of improving the service on a line which connects an important city like Milan to one of the most attractive valleys of the Alps. Of all the Italian State Railway lines, however, the Giovi line, and especially the section Pontedecimo-Busalla, offers the greatest difficulty in operation.

TRAFFIC OF THE HARBOR OF GENOA AND THE GIOVI LINE

The tonnage of the harbor of Genoa which in 1878 amounted to less than a million tons a year, has increased to 7 368 000 tons in 1912, of which 84 percent was imports and 16 percent exports.

There are five railway lines leading to Genoa, Fig. 3, which handle this traffic:—

1—Genoa-Spezia (mostly single track).
2—Giovi line (old) (double track).
3—Giovi line (subsidiary) (double track).
4—Genoa-Asti (single track).
5—Genoa-Ventimiglia (single track).

However, of all these five, the Giovi lines which constitute the direct connection between Genoa and the greatest manufacturing provinces of Italy, Piedmont and Lombardia, handle the most of the freight traffic approximately 80 percent. The Genoa-Spezia

handles eight percent, the Genoa-Asti seven percent and the Genoa-Ventimiglia the remaining five percent. It is to be noted that the Genoa-Asti, although it connects Genoa to Piedmont, has still a very limited service due to heavy grades, single track and poorly

operation with long and heavy freight trains most difficult. The electrified portion of line* has a total length of 23.2 kilometers (14.4 miles) and a difference in level of 1 150 feet between the lowest and the highest stations.

FIG. 1—A TRAIN HAULED BY TWO LOCOMOTIVES, ONE PUSHING AND ONE PULLING
The section of the line shown is between Pontedecimo and Busalla with a grade of 3.5 percent.

ventilated tunnels. At present the electrification of this line is under consideration.

The old Giovi line opened to service in 1853, was proposed and built by the famous statesman Cavour who even that early foresaw the importance of the harbor of Genoa in the industrial development of Italy. It is a mountain road which rises from the sea level, crosses the Appennines and descends in the

On account of the great difficulty in operating with steam locomotives and because of the continuous growth of the traffic in the harbor of Genoa, the Giovi subsidiary line was built in 1889. This line is also a double track line. It branches off the old Giovi line, runs parallel to it on the other side of the valley, crosses the mountain pass through a tunnel of 8.298 kilometers (5.15 miles) in length and then joins the

TABLE I—SUMMARY OF ITALIAN STATE RAILWAY ELECTRIFICATIONS*

Lines	Milano-Varese	Valtellina (13) (Lecco-Sondrio-Chiavenna)	Giovi (Genoa to Ronco)	Bussoleno Bardonecchia	Savona-Ceva	Monza-Lecco	Bardonecchia-Modane
Year electrified	1901	1902	1910-11	1912	1914	1914	[illegible]
Length in miles—single track	79.2	[illegible]	28.8	[illegible]	[illegible]	27.4	23.6
Maximum grade in percent	1	[illegible]	3.5	[illegible]	2.5	1.2	[illegible]
Line voltage	650	3000	3000	[illegible]	3700	3400	3300
Frequency cycles per second	Direct current	15	15	16	[illegible]	15.8	[illegible]
Number of substations	7	11 (1)	4	[illegible]	5	[illegible]	0 (14)
Total capacity of substations—Kw	11 000 of which 1000 is a reserve (3)	7500 of which 1480 is a reserve (4)	12 000 of which 3000 is a reserve	15 000 of which [illegible] is a reserve	15 000 of which 3750 is a reserve	15 750 of which [illegible] is a reserve	0 (14)
Transmission voltage	45 000	20 000	13 000	50 000	50 000	[illegible]	50 000
Total capacity of power-house in Hp	20 000 of which 5000 is a reserve	6000 of which 2000 is a reserve	12 000 of which 6000 is a reserve	[illegible] (5)	[illegible] (6)	[illegible]	[illegible] (7)
Energy produced in 1912-1913—million Kw-Hr.	8.5	5.7	9.0	4.1 (8)	——	....	——
Number of Locomotives	47 (13)	24	24	10	21	[illegible]	8 (9)
Miles run during 1912-1913	1 380 000	414 000	580 000	[illegible]	——	——	——
Capacity of locomotives—Hp	18 200	22 000	48 000	32 000	18 000	[illegible]	16 000 [illegible]

*The Simplon Line, although run for half its length in Italian territory, is not included [illegible] operated by the Italian State Railway.

1—To this number must be added a portable substation used as reserve. 2—This line will be supplied [illegible] substation of the Bussoleno-Bardonecchia Line. 3—To these figures should be added [illegible] 4—These figures include the portable substation. 5—At present the current for this line is supplied [illegible] This is only a temporary arrangement. 6—Energy is supplied by the power house of the [illegible] 7—The electric service on the whole line was started in October, 1913. [illegible] Estimated figures, as service is not started yet. 10—Includes [illegible] 11—[illegible] them to be connected and supplied with energy from [illegible] Company, which reserves for this service 4 000 kw with peaks of a 5 000 kw. 13—Some of these are passenger motor-cars capable of hauling several passenger cars. 14—On these lines the electric service will be started shortly.

valley of the river Po. A profile of the Giovi line is shown in Fig. 4. It has maximum grades of 3.5 percent, six tunnels, of which the longest, the Giovi tunnel, is 3.258 kilometers (2.02 miles) in length, with 2.9 to 3.0 percent grades and numerous curves of 400 meters (1310 feet) radius. These conditions make

old line again. It serves the same purpose as the old line but offers considerably better service conditions having a greater number of uniform grades not exceeding 1.6 percent and reaching only 1.16 percent in the longest tunnel. The total length from where it

*From Genoa to Sampierdarena the line is not electrified.

branches off is 22 kilometers (13.7 miles) and the highest point is 324.64 meters (1060 feet) above sea level.

Although the harbor of Genoa was connected to the valley of the river Po by these two double track lines, a plan view of which is shown in Fig. 5, and by the Genoa-Asti line, in 1906 the steam service began to show its limitation in handling the traffic so much that a special committee ordered by the Government to study the railway problem of the harbor of Genoa arrived at the conclusion that there was an immediate necessity for building a new line to take care of the increasing tonnage, the two

FIG. 2—LINES OF THE ITALIAN STATE RAILWAY IN NORTHERN ITALY ALREADY ELECTRIFIED OR BEING ELECTRIFIED

old Giovi lines being near the saturation point of traffic. At that time during a part of the year there was a great accumulation of goods on the docks and piers of Genoa awaiting shipment by rail, causing great damage and loss. This accumulation of goods reached a maximum during the period from October to January so that the docks, although very large, began to be insufficient, as is seen in Fig. 6; in short, the deficiency in the capacity of the railway line was creating a serious congestion in one of the most important harbors of the country.

In 1906-7 the maximum quantity of goods accumulated in the docks amounted to 575 000 tons with an average of 450 000 tons between October and January. To improve conditions at the end of 1907 a new type of steam locomotive, especially designed for this service by the Italian State Railway was put in service, producing a considerable improvement. These locomotives were of the compound, four cylinder type and had the following characteristics:—

Five coupled axles.
Weight of locomotive on drivers, 75 tons (metric).
Weight of tender fully loaded, 28 tons (metric).
Total boiler surface, 222.3 square meters (2 060 sq. ft.).
Max. steam pressure, 16 kg. per sq. cm. (229 lbs. per sq. in.).
Diameter of high pressure cylinders, 0.375 meters (14.7 inches).

FIG. 3—MAP OF ALL RAILWAY LINES LEADING TO GENOA

Diameter of low pressure cylinders, 0.61 meters (24 inches).
Length of stroke, 0.65 meters (25.6 inches).
Diameter of wheel (when new), 1.35 meters (53 inches).

During the official tests carried out by the Italian State Railway on these locomotives the following results were obtained:—

1—When hauling a train of 204 metric tons (exclusive of locomotive):
Speed on 2.5 percent grade = 40 km. (25 miles) per hour.
Drawbar pull = 5 500 to 6 000 kg. (12 200 to 13 400 lbs.).

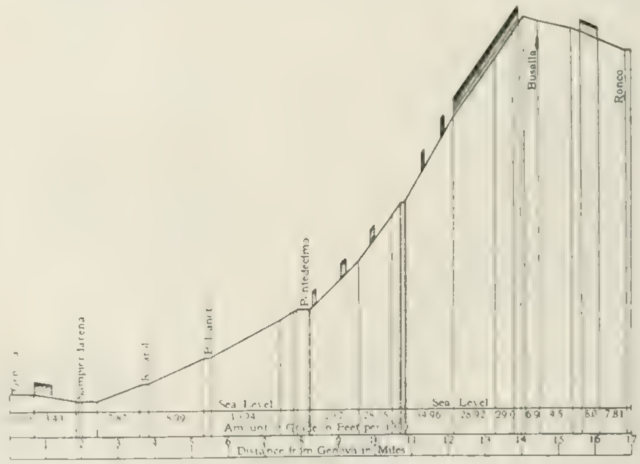


FIG. 4—PROFILE OF GIOVI LINE

Indicated horse-power = 1 200.
Useful power (brake horse-power) = 800.
2—When hauling a train of 272 metric tons (exclusive of locomotive):
Speed on 2.5 percent grade = 25 km. (15.5 miles) per hour.
Drawbar pull = 7 500 kg. (16 600 lbs.).
Indicated horse-power = 900.
Useful power (brake horse-power) = 650.

These new locomotives on the old Giovi line

could haul at the speed of 25 km. (15.5 miles) per hour the following loads:—

Single locomotive ....170 tons (metric)
Two locomotives ....310 tons (metric)
Three locomotives ....450 tons (metric)

By the use of these more powerful locomotives it was possible in 1907-8 to reduce the material piled up in the harbor to 430 000 tons and 350 000 tons, the maximum and average values, respectively, of goods lying in the docks of the harbor during the months October to January. However, this improvement did not last long owing to the continued increase in tonnage, and in 1909-10 the quantity of goods at the docks reached 545 000 and 484 000 tons maximum and average values, respectively. This condition, of course, represented an enormous loss to trade in general by the damage and deterioration of perishable goods.

FIG. 5* PLAN OF GIOVI ELECTRIFICATION

FIG. 6—A VIEW OF THE HARBOR OF GENOA

Showing the congested condition of the docks due to the inadequacy of the steam roads to handle the traffic.

ELECTRIFICATION OF GIOVI LINE

This state of affairs and the conclusions arrived at by the committee appointed by the Government brought about the decision to build another subsidiary line to take care of the natural and continual growth of one of the most important harbors of Italy. This new line, called "The Direct Line," was to be a double track line with low grades and to cross the Appennines through a tunnel of 19 km. (11.8 miles) in length. The estimated cost was 30 million dollars and the necessary appropriation was voted by the Italian Parliament. However, the above mentioned committee in its report to the government, in consideration of the fact that the building of this new direct line with such a long tunnel would require many years, and having in mind the successful experiments carried out on the Valtellina and Simplon electric lines, suggested, besides other improvements, the electrification of the old Giovi line as the means of increasing its capacity.

For this electrification, the three-phase, 15 cycle system was chosen in consequence of the satisfactory results obtained on the Simplon and Valtellina lines. Besides it was decided to increase the speed of the trains on this line to 45 km. (28 miles) per hour on the up grade and to increase the draw-bar pull of the locomotives to the maximum value allowed by the type of rolling stock in service and thereby increase the capacity of the line.

*Figs. 5, 9, 10, 11 and 12 by courtesy of the *Railway Age Gazette*

The Westinghouse type FS—050 locomotive, Fig. 7, having two running speeds of 22.5 and 45 km. (14 and 28 miles) per hour, was chosen for this service. This locomotive, was designed by Mr. K. de Kando and built by the Societa Italiana Westinghouse at Vado Ligure, Italy. Each locomotive is equipped with two 3 000 volt, 25 cycle, slip-ring induction motors. The characteristics of the locomotive are as follows:—

Five coupled axles.
Weight of locomotive on drivers, 60 tons (metric).
Diameter of wheels when new, 1.07 meters (42.5 inches).

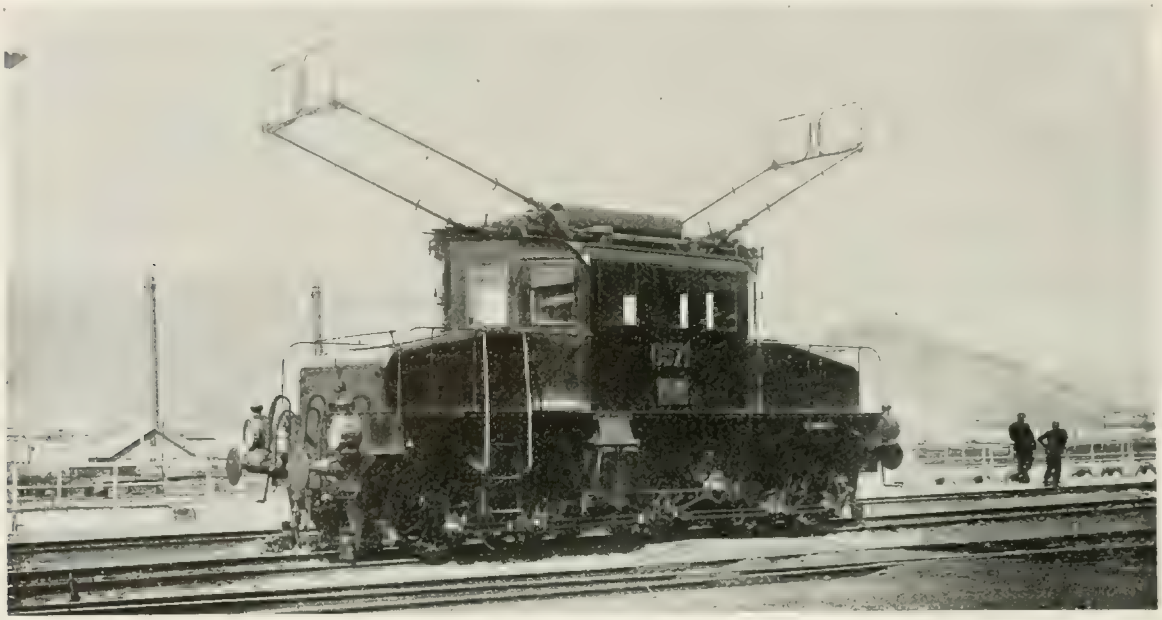


FIG. 7 WESTINGHOUSE LOCOMOTIVE FOR SERVICE ON THE MOUNTAINOUS GIOVI LINE

The motors are connected to the wheels by a special triangular yoke, Fig. 8.

With the standard composition of trains (which is the maximum allowed by the couplings of the cars, but which could be increased as far as the locomotives are concerned as shown by tests when running at 45 km. (28 miles) per hour), the maximum horse-power absorbed by the locomotive is 1 770. When starting the same train on a grade of 3.5 percent, the power absorbed is 2 180 horse-power.

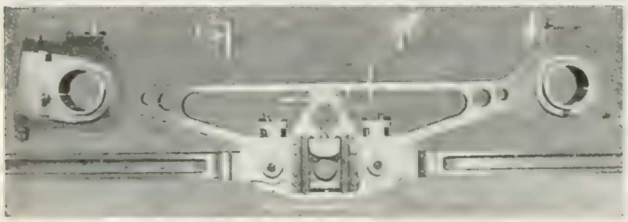


FIG. 8—SPECIAL YOKE BY WHICH THE MOTORS OF THE LOCOMOTIVE ARE CONNECTED TO THE WHEELS

Electric service on the Giovi line was started in 1910 and the capacity of the locomotives was fixed as follows:—

Single locomotive ....190 tons (metric)
Two locomotives ....380 tons (metric)
Three locomotives ....530 tons (metric)

RESULTS OF THE ELECTRIFICATION OF THE GIOVI LINE CONSIDERED FROM AN OPERATING VIEWPOINT

The increased capacity of the line is due to the greater power of the electric as compared to the steam locomotives. This greater power is the result of the increase in speed and tractive effort. The increase in speed has allowed a larger number of trains with a smaller number of locomotives and the increase in tractive effort has allowed greater train weights; therefore a larger number of cars have been handled over this line. The peculiar condition of the line allows the verification of the calculated increase in the capacity of the line after the electrification. This is due to the fact that the line serves a harbor where the traffic is on the increase all the time and also to the existence of the Subsidiary Giovi line.

As soon as the electrification rendered the service on the old line easier, the increase in traffic of the harbor of Genoa was taken care of by the electrified line, and besides, a part of the traffic of the Subsidiary Line also was routed over the old line once it was electrified.

INCREASE IN SPEED

The increase in the running speed of the trains was rather large. The steam locomotives had a maximum running speed of 25 km. (15.5 miles) per hour on the highest grades. The electric locomotives ran at 45 km. (28 miles) per hour even on the 3.5 percent grades. Similarly on the down grades, owing to the electric braking with the regeneration of power, and to the constant speed and absence of shocks it was possible to allow a speed of 45 km. (28 miles) per hour for passenger trains where the maximum speed allowed for the same trains with steam service was 30 km. (18.6 miles) per hour. Besides, with the steam

service there was prescribed a safety stop for all trains on a level section of the line about half way. This compulsory stop has been made unnecessary with the electric service.

If the schedule speed of the trains is considered on this section of the line the following figures obtain for an up-grade hauling:—

Steam service—freight trains, 20.8 km. (12.9 miles) per hour.
Steam service—passenger trains, 22.3 km. (13.9 miles) per hour.
Electric service—freight trains, 39.1 km. (24.3 miles) per hour.
Electric service—passenger trains, 39.1 km. (24.3miles) per hour.

This represents increases of 88 percent and 75.5 percent, respectively, and is also partly due to the shorter time taken by the electric locomotive for accelerating.

INCREASE IN THE NUMBER OF TRAINS

This increase is clearly shown by the train sheets, Figs. 9 and 10, for steam service in its last year 1910, and of the electric service now in operation. With the steam service it was possible to run a maximum of 28 up trains and 23 down trains per day, spread over a period of 20 hours. However, the average number of trains per day was considerably lower. In the last year of steam service 1909-10 a total of 8 793 up and 7 792 down trains were run, corresponding to an average value of 24 up and 21.3 down trains per day. With the electric service in 1911-12 there were run 12 024 up and 8 050 down trains corresponding to an average value of 33 and 22 per day; that is, an increase of 37.5 percent in the number of up trains which constitutes the increase in the capacity of the line. It was not necessary to increase the number of the down trains as the composition of trains with steam service was already very large, the largest number of cars being empty on the down trip.

With steam service the figures given above could not be increased to any appreciable extent, both because of the limited speed of the locomotive and the difficulty of ventilating the Giovi tunnel. The steam service shown in the schedule, Fig. 9, was only possible by strong artificial ventilation of the tunnel by means of a special blower driven by a 500 horse-power motor.

With electric service the average figures given above refer to a schedule spread over a period of 17 hours per day, Fig. 10, and therefore they could be increased considerably; for instance, during the month of April, 1913, on the same section of the line referred to, there were run 223 trains more than shown in the schedule, corresponding to an average of 7.45 trains per day, of which 5.2 were up and 2.25 down trains. The maximum number of additional trains per day during the same month besides the trains shown in the schedule, was 13, of which nine were up and four down trains. Therefore, the average and maximum values for the month of April would be 38 and 42, respectively, which compared to the 28 of the steam service represents an increase of 36 and 50 percent, and when it is considered that electric service is used for 17 hours only instead of 20, the increase amounts to 61 and 77 percent. The same results were obtained during some days in the month of August when numerous extra trains were run for the purpose of testing new electric locomotives.

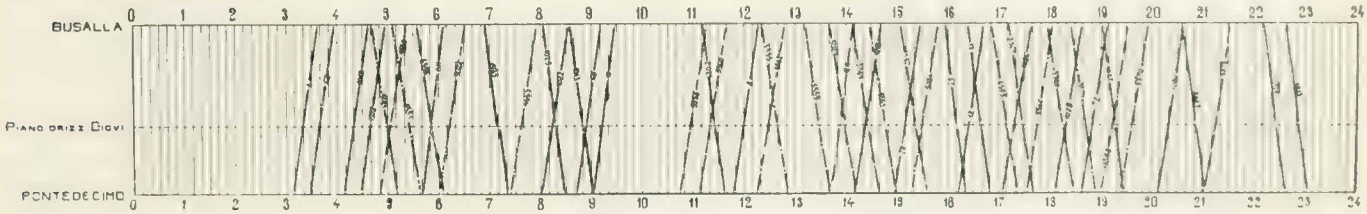


FIG. 9—SCHEDULE OF STEAM SERVICE ON THE OLD GIOVI LINE FOR THE SUMMER OF 1914 ON THE SECTION PONTEDECIMO-BUSALLA

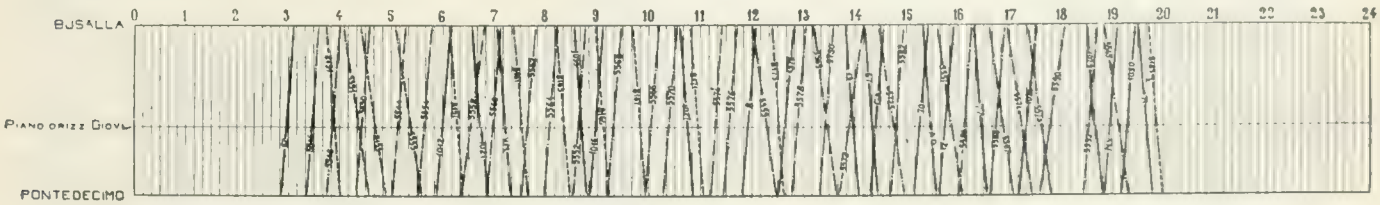


FIG. 10—SCHEDULE FOR ELECTRIC TRAINS ON THE SECTION PONTEDECIMO-BUSALLA, YEAR 1914. COMPARE WITH FIG. 9 FOR STEAM SERVICE

However, these figures do not represent the maximum obtainable with electric service. This maximum was determined when making the project for the electrification of the line and of all the fixed installations like central station, sub-stations and transmission lines which were designed for a service having trains starting every 10 or 15 minutes the load curves for which are shown in Figs. 11 and 12. Such service, is possible both on account of the size of the electric installations and of the block system existing on the line. The time taken to go through the tunnel is only nine minutes; therefore, with trains starting every ten minutes, a train would leave the station at the entrance of the tunnel when the preceding train reached the telegraph station at the other end.

Assuming a utilization coefficient* of the Italian State Railway of 0.70 and assuming 20 working hours per day, as was the case with steam service, the average number of daily trains with electric service would be:—

Trains leaving every 15 minutes $0.7 \times 20 \times 4 = 56$
Trains leaving every 10 minutes $0.7 \times 20 \times 6 = 84$

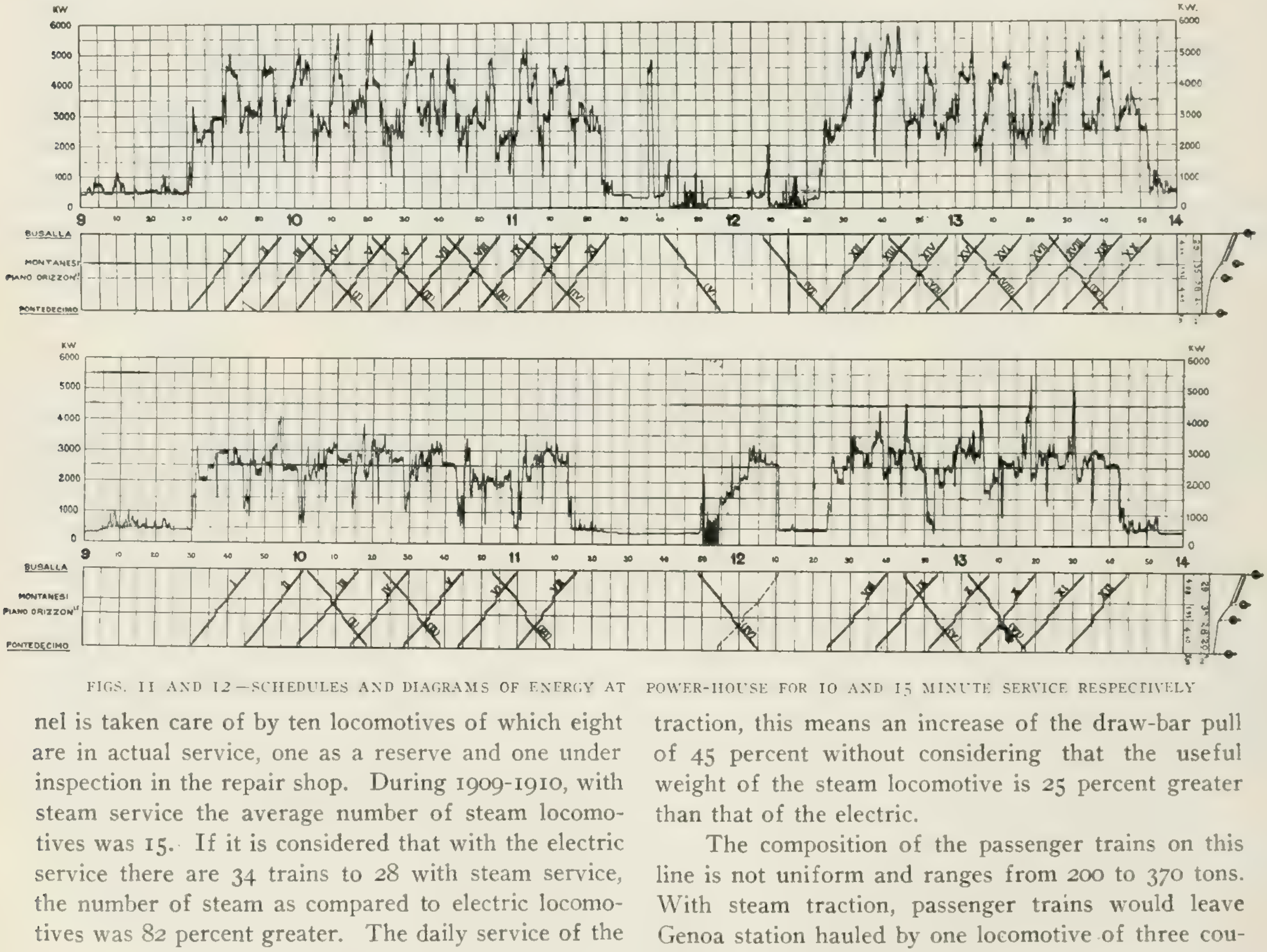
These figures as compared to 28 of the steam service represent an increase of 100 and 200 percent, respectively.

ELECTRIC LOCOMOTIVES

On account of the higher speed of the electric locomotives and their suitability for shunting operations in the stations, it was possible with electric traction to make a rather large reduction in the number of locomotives and, therefore, in the number of train crews. At present the service through the Giovi tunnel is taken care of by ten locomotives of which eight are in actual service, one as a reserve and one under inspection in the repair shop. During 1909-1910, with steam service the average number of steam locomotives was 15. If it is considered that with the electric service there are 34 trains to 28 with steam service, the number of steam as compared to electric locomotives was 82 percent greater. The daily service of the electric locomotive could easily be increased, working 24 hours, because the maximum temperature of the electric motors was only 73 degrees C. after 16 up and 16 down trips hauling normal weight train and regenerating energy on the down trip, the last two trips having been made without forced ventilation of the motors.

TRACTIVE EFFORT AND COMPOSITION OF TRAINS

A comparison between the maximum composition of trains permissible with steam locomotives and the standard composition of trains prescribed for the electric locomotives, Table II, as allowed by the existing type of rolling stock, shows how much more powerful the electric locomotives are. Considering that with electric operation there is permissible an overload of ten tons, there is on increase as compared to steam operation of 17.5, 26 and 20 percent, respectively, for the arrangement in Table II. However, as already pointed out, the draw-bar pull of the locomotive and the capacity of the motors are far greater, so that it was possible to haul with two locomotives on the same section of the line trains up to 450 metric tons at 45 km. (28 miles) per hour. As compared with steam traction, this means an increase of the draw-bar pull of 45 percent without considering that the useful weight of the steam locomotive is 25 percent greater than that of the electric.



FIGS. 11 AND 12—SCHEDULES AND DIAGRAMS OF ENERGY AT POWER-HOUSE FOR 10 AND 15 MINUTE SERVICE RESPECTIVELY

The composition of the passenger trains on this line is not uniform and ranges from 200 to 370 tons. With steam traction, passenger trains would leave Genoa station hauled by one locomotive of three coupled axles, and when reaching the section of the line through the Giovi tunnel, two other locomotives of five coupled axles would be added, one pulling and one pushing. Only very light trains would be hauled by two locomotives. With electric traction, however, all passenger trains are hauled by two locomotives.

As regards freight trains with steam service, nearly all of them were hauled by three locomotives, one pulling and two pushing. With electric service,

*Utilization coefficient is the ratio between the average daily number of trains actually run and the number of trains given in the schedule.

the freight trains have a uniform composition of 380 tons (composed mostly of freight cars of the same type loaded with coal) and are hauled by two locomotives one pushing and one pulling. For freight trains, the cars not having air brakes, a single locomotive is not allowed except with one locomotive at the rear of

TABLE II—WEIGHT OF TRAIN EXCLUSIVE OF LOCOMOTIVE

Number of Locomotives	Steam.	Electric.
Single locomotive	170 tons	190 tons
Two locomotives (one pulling and one pushing)	310 tons	380 tons
Three locomotives (one pulling and two pushing)	450 tons	530 tons

the train. Referring to Table II and considering that the electric locomotive (type 050) weighs 60 tons, while the steam locomotive (type 470), including the tender with two-thirds load of water and coal, weighs 97 tons, it will be found that the steam locomotive represents 57, 62.7 and 64 percent, respectively, of the hauled weight while the electric locomotive represents only 30, 30.8 and 33.5 percent. As compared to the total weight of the trains, the weight of the electric locomotive represents only 23.1, 23.5 and 25 perecnt.

The first steam locomotive used on the Giovi line was a locomotive especially designed by Stephenson having two coupled axles and known as the Mastodon, Fig. 14. Two of these locomotives coupled together weighed 54 tons and could haul a train of 88 tons at a speed of 20 km. (12.4 miles) per hour. Therefore, the ratio of the hauled weight to locomotive weight was $88 \div 54 = 1.63$. Later these locomotives were replaced by more powerful ones of the Beugnot type, Fig. 15. They had four coupled axles, weighed 51 tons and had a tender which fully loaded weighed 24 tons. At 25 km. (15.5 miles) per hour they could haul on the Giovi line a train of 120 tons. The ratio of weights was $120 \div (51+24) = 1.6$. These locomotives were again replaced by new ones of the Sigl type, Fig. 16, with four coupled axles; they weighed 53 tons and had a 27 ton tender. They could haul 130 tons at 25 km. (15.5 miles) per hour. The ratio of weights in this case was $130 \div (53+27) = 1.625$.

The last type of steam locomotives (type 470) had five coupled axles and, including the tender fully loaded, weighed 103 tons and could haul a train of 170 tons. The ratio was $170 \div 103 = 1.65$. This same ratio of weights for the three-phase locomotive (type 050) is $190 \div 60 = 3.17$, without considering that the speed has been increased from 25 to 45 km. (15.5 to 28 miles) per hour. This shows the superiority of the system of traction chosen for this line and it also shows that the steam locomotive after 50 years of improvement is still unsuitable for lines with heavy grades. A comparison of the two locomotives is shown in Fig. 17.

NUMBER OF CARS

It is evident from what has been said that the number of cars carried over this line has been increased greatly by electrification. During the last year of steam traction there was on this line a total traffic of 109 963 cars (passenger and freight) on the up grade and of 133 000 in the other direction. In 1911-12 after the electrification these numbers increased to 172 063 and 146 113 an increase of 56.5 and 10 percent, respectively, without considering that the weight of the freight cars was also increased. And if the freight traffic on the up grade only is considered, there was an increase of 109 percent. This would correspond to a daily service of 165 cars with steam operation and 346 with electric. However, the electric service as developed experimentally during the month of August, 1913, for 17 hours daily represents an increase of 218 and 214 percent. Even this does not show the maximum with electric service.

FIG. 13 A GROUP OF THREE-PHASE LOCOMOTIVES USED ON THE GIOVI LINE OF THE ITALIAN STATE RAILWAY

CAPACITY OF THE LINE

In comparing the capacity of the Giovi line after the electrification to that before, the steam service in

1909-10, the last year of the steam traction, and the results of the electrification in the first year of the service 1911-12, together with the service as tried experimentally during August, 1913, and the maximum permissible service as estimated by the Italian State Railway, will be used. Only the traffic on the up grade will be considered, which is what determines

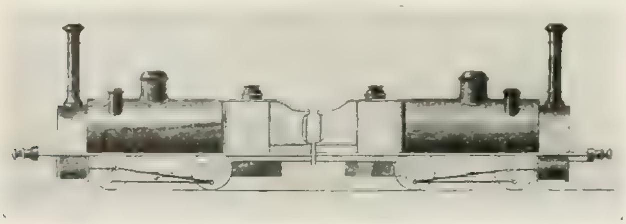


FIG. 14—ORIGINAL STEPHENSON LOCOMOTIVE ESPECIALLY DESIGNED FOR SERVICE ON THE GIOVI LINE

the capacity of the line, and it will be limited to 20 working hours per day, although it should be understood that with electric operation this limitation to 20 hours is not necessary. It was necessary with steam operation in order to allow time for repairs and upkeep of the tracks in the tunnel as, on account of the smoke, the men could not work in it during the service hours. Besides this only the hauled weight of trains, which is the most important, will be considered.

Electric service 1911-12—As already stated the total number of cars was 172 063, divided as follows:—

Passenger and baggage cars	45 927
Freight cars	105 132
Fast freight cars	16 807
Empty cars	4 107

The weight* of these cars can be assumed as follows:—

Passenger and baggage cars	30 tons
Freight cars (coal cars mostly)	21 tons
Fast freight cars	12 tons
Empty cars	8 tons

The total movement of cars then is:—

Passenger and baggage cars	1 380 000 tons
Freight cars	2 210 000 tons
Fast freight cars	203 000 tons
Empty cars	32 800 tons
Total	3 825 800 tons

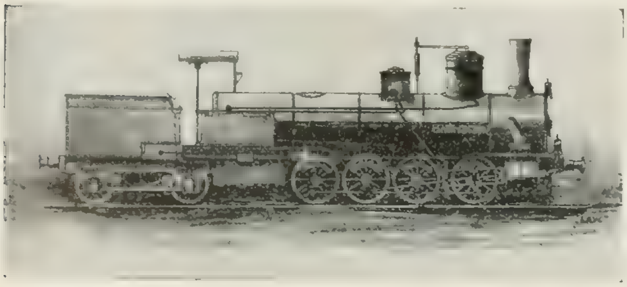


FIG. 15—BEUGNOT STEAM LOCOMOTIVE
This succeeded the original Stephenson type.

Experimental Electric Service in August, 1913—The experiments carried out gave the following figures:—

41 trains, 644 cars, 17 hour service	13 640 tons
40 trains, 636 cars, 17 hour service	13 712 tons

These figures reduced to a year give 5 000 000 tons for 17 hours' service per day.

Now, assuming the same weight of cars,* the following figures will hold for steam operation 20 hours per day:—

38 916 freight cars	840 000 tons
19 560 fast freight cars	235 000 tons
49 624 passenger and baggage cars	1 485 000 tons
1 854 empty cars	14 800 tons
Total	2 574 800 tons

Comparing this figure with that of electric service reduced to 20 hours per day it will be found that the service during the year 1911-12 represents an increase of 75 percent and the experimental service during the month of August, 1913, an increase of 128 percent.

Intensive Electric Operation 15 and 10 Minute Trains—In comparing this service with steam, the maximum capacity of the latter as outlined by the Government Committee will be assumed and two locomotive operation will be considered throughout. With 15 minute service during 20 hours, there would be 80 trains per day, of which 15 are passenger and 65 freight. Assuming a utilization coefficient of 0.70, $65 \times 0.7 \times 380 = 17\,300$ tons daily, or 6 310 000 tons

FIG. 16—SIGL STEAM LOCOMOTIVE
A later development than the Beugnot.

yearly. With service every 10 minutes there would be 120 trains, of which 105 are freight, equal to 10 200 000 tons yearly.

Maximum Steam Service—Twenty-two trains of 310 tons each, or 6 820 tons daily=2 409 000 tons yearly. Therefore, assuming that the passenger trains are the same in both cases there is an increase in capacity of 153 percent with 15 minute service, and 310 percent with 10 minute service. These results are so enormous that they do not require any amplification. Suffice it to note that it will take many years before the traffic of the harbor of Genoa will be such as to require the maximum capacity of the Giovi line. Considering that on account of these results the Italian State Railway has electrified the Subsidiary Giovi line and is considering the electrification of the Genoa-Asti, it will require many years before the new direct line will have to be built. In Table III are condensed the figures given in the preceding pages.

EFFECTS ON THE HARBOR OF GENOA

The effect of the increase in capacity of the Giovi line on the quantity of goods accumulated on the docks

*In all the data of this article the weights are given in metric tons.

*This is in favor of the steam traction as the weight of the cars has been increased during the last few years.

can easily be seen from the diagram of the goods accumulated in the docks awaiting shipment by rail, Fig. 19. This was published by the railway administration in its report to the Minister of Public Works, 1911-12.

TABLE III—RESULTS OF ELECTRIFICATION OF THE GIOVI LINE
(Section Pontedecimo Busalla.)

		Steam Traction	Electric Traction	Difference in Percent
Total weight of loco. including tender—tons		103	60	—42
Adhesive weight of loco.—tons		75	60	—20
Maximum speed (up grade) km per hour or miles per hour		25 km. (15.5 m.)	45 km. (28 m.)	80
Commercial speed (up grade) a—Passenger trains		22.3 km. (1.38 m.)	39.1 km. (24.3 m.)	75
b—Freight trains		20.8 km. (1.29 m.)	39.1 km. (24.3 m.)	88
Number of up trains according to schedule		28(1)	34(2)	21.5
Actual number of trains run		24(3)	33(4) 42(5) 41(6)	37.5 75.5 71
Maximum number of up trains		37(7)	56(8) 84(9)	52 127
Ratio between number of loco. in service and No. of trains as given in schedule		5.35	2.49	—45
Weight of trains	single loco	170 tons	200	17
	double loco	310 tons	390	26
	triple loco	159 tons	450	20
Ratio in percent of weight of loco to hauled weight	single loco	57	30	—47.5
	double loco	62	30	—51
	triple loco	64	34	- 47.5
Ratio in percent of loco weight to weight of train	single loco	36.3	23.1	—36 5
	double loco	38.5	23.6	—39
	triple loco.	38.3	25.4	—35.5
Ratio of hauled weight to locomotive weight.		1.65(10)	3.17	92
Number of freight cars (up trains)		165(3)	346(4) to 525(6)	100—218
Capacity of line	Actual freight and passenger service.	7054(3)	12 331(11) 16 052(12)	75 128
	Maximum freight service	6820(7)	17 300(8) 27 900(9)	153 310

(1)—Schedule for summer 1910. (2)—Schedule for winter 1913. (3)—Average for year 1909-10. (4)—Average for year 1911-2. (5)—Service in April 1913. (6)—Service in August 1913. (7)—As outlined by Government Committee. (8)—Service every 15 minutes. (9)—Every 10 minutes. (10)—Locomotive (gr. 470). (11)—Average of year 1911-12 reduced to 20 hours service. (12)—Service in August reduced to 20 hours.

FIG. 17—A COMPARISON OF THE MOST MODERN TYPE OF STEAM LOCOMOTIVE WITH THE ELECTRIC
The latter, while practically only half the size of the former outfit, is in the neighborhood of twice the capacity.

This diagram compares the year 1909-10, the last of steam service, with the year 1911-12, the first of electric. From this diagram it can be seen that the maximum quantity of accumulated goods reached 540 000 tons in 1909 and only 300 000 tons in 1911. And considering the worst period of the year, October to January, the average values of accumulated goods was 484 500 and 246 600, that is, a maximum of 80 percent and an average of 96.5 percent more goods accumulated during the steam service.

In this case electrification, besides solving a railway problem, increasing the capacity of a line so as to take care of the growth of the traffic for many years to come, has solved at the same time a different but serious problem, the excessive accumulation of goods in the docks during a part of the year; an accumulation which caused great inconvenience and very considerable loss. Thus the electrification has produced an increase in the capacity of the Giovi line and indirectly an increase in the capacity of the harbor of Genoa and very likely may do away with the building of the direct line with the 20 km. (12.4) mile tunnel which was estimated to cost not less than $30 000 000.

CONCLUSION

The above mentioned results obtained by the electrification of the Giovi line constitute one of the best examples of the suitability of the electric motor for service rendered up to now by the steam engine. The Giovi line has been regenerated by three-phase electrification. The line was of such importance to traffic that its electrification was decided upon to improve existing conditions, even if that would mean an increase in the operating expenses. However, the results from an economic point of view have been far better than expected and have constituted for the Italian State Railway a very great success. A very detailed and careful examination made by the administration of the Italian State Railway has shown that the running expenses, including interest and depreciation on the investment, have been reduced 22.5 percent, notwithstanding the fact that the electric energy is produced by a steam-electric plant and that the sta-

tion capacity is not yet fully utilized. What Galileo Ferraris, in 1904, stated in his paper on the "Transmission of Electric Energy," has been realized in this electrification; namely, that electrification would render traction most economical in those cases where steam traction was most expensive.

As regards the relative merits of the various systems, the Italian State Railway are sufficiently satisfied with the three-phase system to extend it to all their lines as conditions will require it. Having already in service 135 three-phase electric locomotives, of which 110 are of the Giovi type with a total capacity of 261 200 horse-power, they are considering the electrification of new lines not on theoretical considerations but from the results of actual experience. On account of the large increase in the capacity of the lines through three-phase electrification, it will be unnecessary to double the track on single track lines where the traffic is getting too heavy and where the expense of doubling the track would be very high; besides, on account of the elimination of smoke they will be able to improve greatly the service on lines with many tunnels as is the case on most Italian lines. To this will be added the advantage of a reduction in the running expenses and, by utilizing to a larger extent the hydraulic power not yet developed, they may reduce the importation of coal which represents a heavy expenditure for the country. Again it is not simply the large saving due to the characteristics of this system, such as the lightness of the locomotive and the regeneration of power, but more especially the characteristic of maintaining high speeds on the up-grade with high tractive effort and high efficiency, which determines the capacity of the lines.

It is true that the Giovi section of the line is especially suited to three-phase traction, but the electrification of the other sections of the line which are nearly level and which are served by the same locomotives has shown (as in the Valtellina lines) that the advantages of a light and powerful locomotive having few and fixed speeds can be felt even on level lines where the traffic is heavy enough to warrant their electrification.

Before closing it will not be out of place to say a few words on the much discussed question of the choice of systems, which until recently has been based more on theoretical considerations than on actual results. During the last ten years the discussions on the different systems of electric traction have been very active and have aroused probably more interest than any other proposed application of electricity. Examining carefully and without conscious prejudice the various arguments which have been put forth in these discussions, it will be found that they have been largely of a literary nature, based upon theoretical preferences rather than on actual results. Those who have followed all the details will recall that most of the deductions and conclusions were arrived at by means of calculations which though very exact in their development were, however, based on certain arbitrary assumptions which were rarely realized in practice. A few years ago, the end of the direct-current system was prophesied as it was then thought impracticable to use voltage higher than 600 or 700 volts. Similarly the single-phase locomotive was considered by some the ultimate solution of the railway problem, while the three-phase system also had its ardent advocates. Even today discussions of these questions are often based on calculated rather than actual results which are seldom known, because of the unwillingness of railway companies using the various systems to divulge their operating costs, which therefore cannot often be used in such discussions; and, further, because the conditions of different lines and in different countries vary to such an extent as to make them incomparable. These are the most important reasons why this general question of the system of traction to be chosen has not yet been solved. The problem was considered at the beginning entirely from the standpoint of electro-technics, as electrical engineers were naturally uninformed as to the technique of railroad operation, and thought it in-

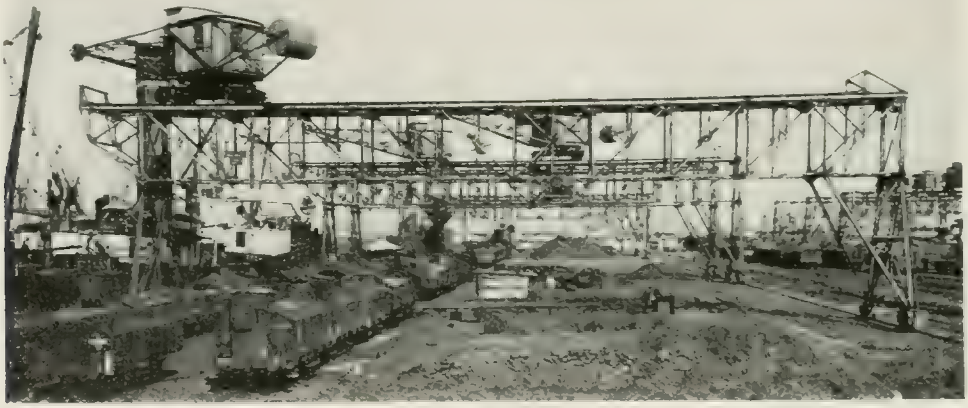


FIG. 18—A VIEW SHOWING THE MAGNITUDE OF COAL HANDLING OPERATIONS AT THE GENOA DOCKS

dispensable that there be only one interchangeable system of traction. In addition many electrical engineers had failed to realize that the introduction of the electric locomotive should be the means to the desired end, and not the final goal to be attained. This state of affairs explains the neglect of many electrical engineers to consider the question of the

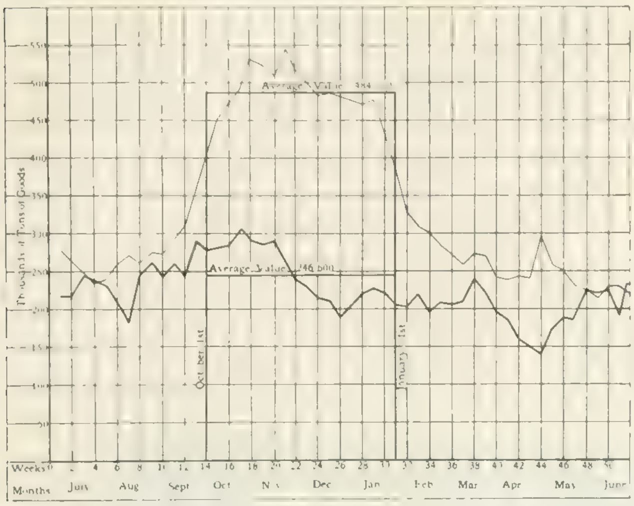


FIG. 19—CURVES SHOWING THE RELATIVE AMOUNTS OF GOODS ACCUMULATED ON THE GENOA DOCKS WITH STEAM AND ELECTRIC SERVICE

The upper curve is for 1909-10, with steam service and the lower for 1911-12 with electric.

weights of locomotives, and also explains the unrealized dreams about revolutionizing the operation of railroads by electric traction. Railway service has arrived at such a high degree of development that it does not permit of sudden or radical changes, as H. Spencer long ago had foreseen.

A step forward, however, as regards the choice of system was made at the Railway Congress at Berne in 1910 and at the International Electrical Congress at Turin in 1911, when it was agreed that each system had its own peculiar field and that the system of traction to be employed is a problem which can be solved only when the conditions in each case are carefully considered. This sane conclusion gave pause to those who had looked forward to the adoption of a single system of electric traction for all the world. In reality this agreement was nothing new, as the policy of choosing the system of traction according to the peculiar conditions of each individual case had already been actually established in many places.

Whatever may be the future development of the various systems, which is very difficult at this moment to foresee, it is a fact that now, after many years, very few results of railroad electrification are available for comparisons. By carefully perusing all the technical literature, although one may find material regarding the results of direct-current and three-phase railway electrifications, there has so far been very little published of the results of single-phase electrification.

If we limit our research to trunk lines, we find the actual results published up to this time are very few. Even in the United States there is not more than one single-phase line, which is really a trunk line, the operating results of which have been published, and that is, the New York, New Haven and Hartford Railroad. It is to be hoped that in Europe also the actual results of single-phase electrification will be published.

So far as information regarding three-phase electrification is concerned, Italy has supplied the most striking example of this system, and for the last ten years official and private publications have supplied all the available technical and economic data and results, and perhaps the reason why these results are not better known is due to the fact that the Italian language is not well known in the technical world and in most industrial countries, but if these results had been better known they certainly would have modified a great many wrong ideas held with respect to that system.

Of all the results of the three-phase system published up to this time, the increase in the capacity of steam lines where the traffic has become too heavy is certainly one of the most important, and we have endeavored to illustrate this result as shown by the Giovi electrification. It is a result that is common to

FIG. 20—DETAILS OF OVERHEAD CONSTRUCTION ON THE THREE-PHASE LINES OF THE ITALIAN STATE RAILWAY

a certain degree to all systems but under the conditions in Italy to a greater extent to the three-phase system. It is hoped that where similar results have been obtained by other systems they be made known to all for the good of the electrical industry.

Reference publication—*Rivista Tecnica delle Ferrovie Italiane*—Anno III, Vol. V, No. 1. Report to the Italian government by the committee headed by Senator Adarnoli.

High Speed Rotary Converters

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The increase in speed of rotary converters for a given rating which has taken place during the past five years followed the increase in steam pressure and the use of superheat in prime movers, and was for the same purpose, that is, to secure higher economy. Before the turbine and superheater came into use, when it was found that an increase of capacity per pound of material could not be obtained in a reciprocating engine by a further increase in speed owing to the non-uniform stresses of reciprocating motion, recourse was had to a higher steam pressure. This higher pressure of course caused higher internal stresses in engine and boiler. One did not hear, however, of more but rather of fewer explosions with the high pressure boilers than with the old low pressure boiler. No one imagined that these internal stresses did not exist and their use was freely permitted. Every one appreciated that the need of balancing an action by an equal and opposite reaction was fully recognized in design.

The modern rotary converter occupies quite as advanced a position in its particular field as does the turbine. It drives nothing mechanically and is driven by nothing and, as the motion of its moving parts is purely rotational, there has been nothing to prevent its speed from being increased to the economical limit. While the peripheral velocities employed in modern standard rotary converters are somewhat higher than those employed in the earlier machines ten or fifteen years ago, they have not been pushed beyond values reached four years ago. The increased stresses due to the increased angular velocity and to the increased beam lengths in the rotating parts are still so very far below the stresses encountered in the turbo-generator as to present a comparatively simple problem in design. With the existing knowledge on the subject, there are no difficult problems in the mechanical design of the rotary converter and no troubles, so far as the writer knows, have been experienced which could be attributed to the high speed itself.

The curves in Fig. 2 are of historical interest and show what is being done and what may reasonably be expected in the relationship between speed and kilowatts. Curve *I*, with the individual ratings as indicated, shows this relationship in 1908-9. In 1909-10 three machines were built, as indicated by the points of curve *II*, of which the 500 and 1 000 kilowatt units were for 60 cycles and the 3 000 kilowatt unit for 25 cycles. Curve *II*, determined by these machines, shows the maximum ratings obtainable without employing commutating poles.

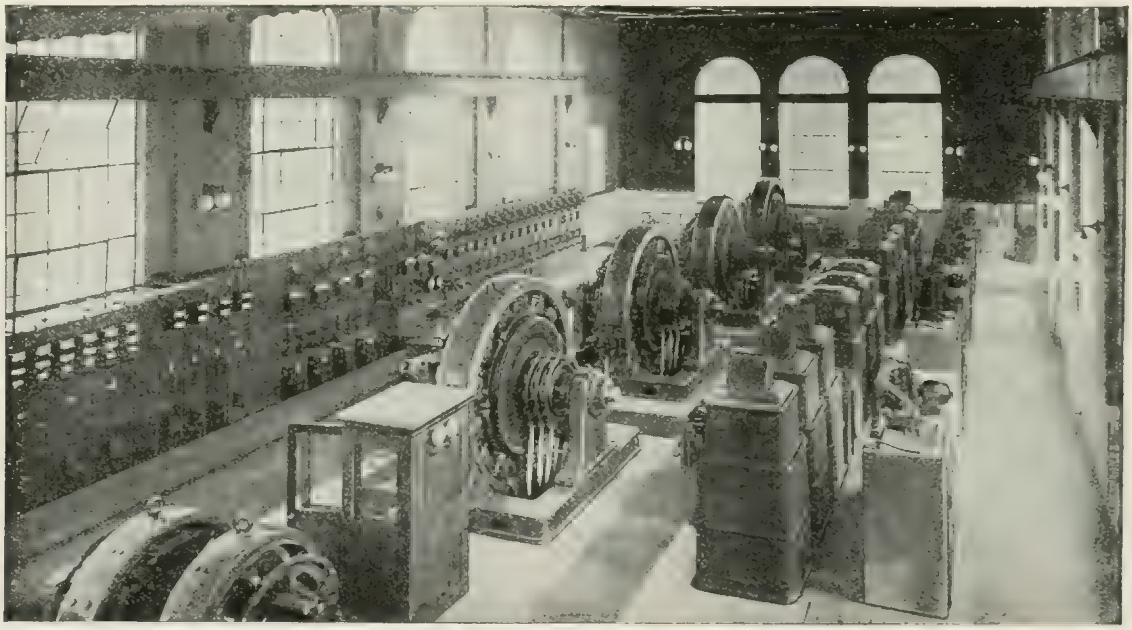

FIG. 1—WINDEMERE SUBSTATION OF THE CLEVELAND RAILWAYS COMPANY
Four 1 500 kilowatt, 60 cycle Westinghouse rotary converters.

After 1911 the principal manufacturers of rotary converters turned to commutating poles. One manufacturer built a line of railway rotary converters as indicated by the points of curve *III*, most of which were for 25 cycles. The 60 cycle machines, one a 1 000 kw at 720 r.p.m. and the other a 1 500 kw at 600 r.p.m., are considerably in advance of this curve. The Westinghouse Company built a line of 25 and 60 cycle commutating-pole rotary converters, indicated by

curve *IV*. The increase in output for a given speed amounted to 33-1/3 percent over the largest possible non-commutating pole machines shown by curve *II*. That these developments were for the sake of economy and that the purchasers secured the full benefit of them is shown by the following data refering to this manufacturers product:—

1—In 1912 the selling price per kilowatt of the total output in rotary converters of this manufacturer was 84.5 percent of the 1911 figure and in 1913 it was only 66.5 percent of the 1911 figure.

2—The weights dropped to from 42 percent to 65 percent of those of the machines on curves I and II, thereby reducing materially the expense of shipping and handling. This reduction in weight resulted partially also from a more extended use of steel in the magnetic circuit at a higher cost per pound.

3—The floor space occupied was reduced to from 47 to 73 percent of the floor space occupied by the machines of curves I and II, resulting in immense savings in the substation costs.

4—The maximum momentary overload guarantee was increased from 75 to 100 percent and in some cases to 200 percent. The 50 percent overload guarantee was increased from one to two hours. In regard to this it should be stated, however, that the majority of the rotary converters in 1908-9 were equally good for these increased overload guarantees had there been a demand for them.

5—The efficiencies were increased. In the case of the 25 cycle converters, the increase amounted to only a few tenths of a percent at full load, though at light loads the increase was material. In the case of the 60 cycle converters, it amounted to from one to three percent at full

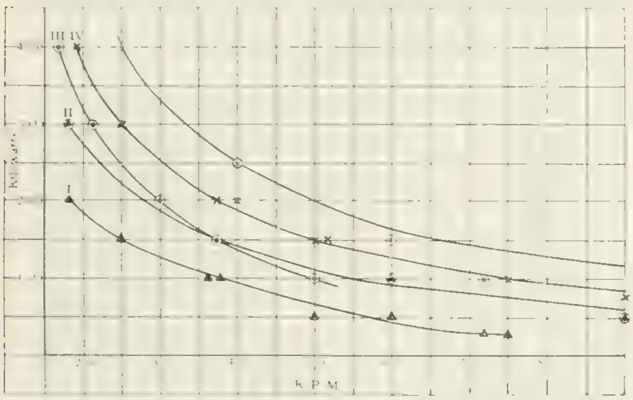

FIG. 2—CURVES SHOWING RELATIONSHIP BETWEEN SPEED AND KILOWATT RATING OF ROTARY CONVERTERS

load. It is really remarkable how the efficiencies of 60 cycle rotary converters have been improved, until now at three-quarters load they are only 1.5 to two percent below and at full load scarcely more than one percent below the efficiencies of the corresponding 25 cycle rotary converters. Comparing an installation of 60 cycle rotary converters and transformers with a corresponding 25 cycle installation, the difference in efficiency is even less, owing to the superior efficiency of the 60 cycle transformers. Mr. L. P. Crecelius, * described a large installation of 1 000 and 1 500 kilowatt, 60 cycle railway rotary converters, shown in Fig 1, which operate by means of transformers from an 11 000 volt transmission line. He gave an overall substation efficiency for the period of one month of 92 percent, which is certainly an achievement.

6—The k.v.a. input required for alternating-current, self-starting has been materially reduced, the reduction amounting to at least 33⅓ percent. None of the 25 cycle machines on curve IV require more than 35 percent of the full load k.v.a. from the line at starting and none of the 60 cycle machines require more than 84 percent.

Obviously, these are the points which should be considered in buying a rotary converter, rather than speed, diameter and length of commutator or armature, volts per bar, brushes per arm, current densities, etc., which may or may not be in accord with one's experience or preconceived ideas. Only those who have worked for a long time with these quantities really know whether the relationship between them is good or bad. Others who attempt to weigh one point of design against another, as though weighing tea or some other commodity, are more than likely to reach a wrong conclusion through inadequate acquaintance with the premises. Even tea is bought by the taste rather than by the pound, by the discriminating drinker; and rotary converters should be bought by their performance rather than by the "volts per bar" or "amperes per arm."*

If a justification for the rotary converters of curve *IV*, Fig. 2, were necessary, it is found in some machines which exceed that curve. As previously mentioned, one manufacturer has built a 1 500 kilowatt, 60 cycle, 600 volt rotary converter at 600 r.p.m. This machine, though operating at the end of a long transmission line subject to frequent disturbances, is giving an excellent account of itself. The Westinghouse Company is building a 1 000 kilowatt, 60 cycle, 600 volt, 900 r.p.m. rotary converter and a 4 000 kilowatt, 25 cycle, 600 volt, 214 r.p.m. rotary converter,

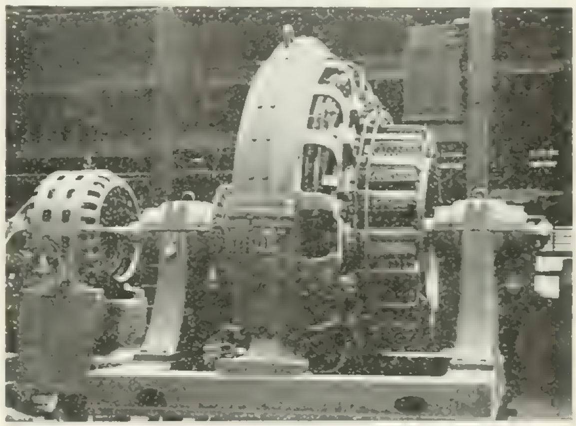

FIG. 3—A 2 500 KILOWATT, 60 CYCLE, 400 R. P. M. WESTINGHOUSE ROTARY CONVERTER WITH INDUCTION MOTOR STARTER

and has already built a 2 500 kilowatt, six phase, 60 cycle, 500 volt, 400 r.p.m. rotary converter. This last named machine determines curve *V*, Fig. 2. Inasmuch as from the point of view of "high speed" this rotary converter is the hardest rated machine which has ever been built, it is described in some detail, giving the results which have been obtained in operation at the Maryville, Tenn., Plant of the Aluminum Company of America, of an installation of nine of these rotary converters since they were started up early in March, 1914.

Four of these machines operate from the four in-

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*In a paper read before the Cleveland section of the American Institute of Electrical Engineers, March 23, 1914.

*In the A. I. E. E. discussion at Cleveland, March 23, 1914, the writer gave a long list of installations of modern high-speed rotary converters, showing how rapid has been the extension in their use, and in a written discussion contributed on June 12, 1914, to the report of the National Electric Light Association's Committee on Electrical Apparatus, referring to synchronous converters versus motor-generators, the writer gave the overall efficiencies, floor space and weights of some existing installations of high-speed rotary converters with step-down transformers.

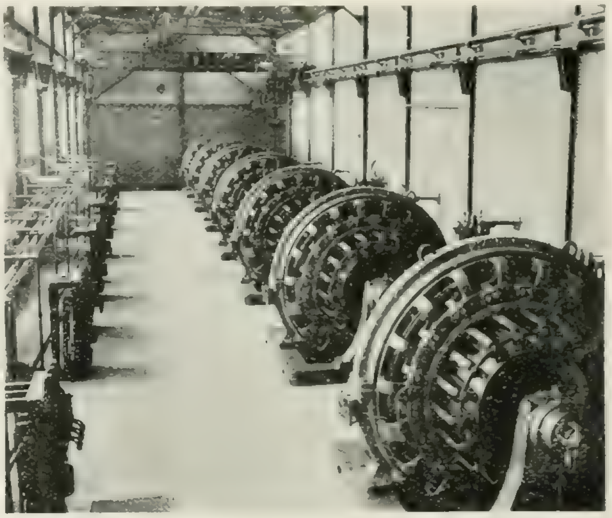
dependent secondaries of each of two three-phase, 10 000 kilowatt transformers; the ninth is a spare. Eight of them were made self-starting from either side and one, for the sake of greater flexibility, was made induction motor starting, with 10 percent greater cost and weight. This latter is shown in Fig. 3. The Aluminum Company prefers to start the one converter by the starting motor and the remainder from the direct-current ends; and the operators have been able to start, synchronize and put load on six converters in seven minutes. One of the features of this machine is its ability to carry 5 000 amperes continuously at 300 volts, 400 volts or 500 volts on the direct-current end when a suitable alternating voltage is applied. It will carry 5 000 amperes at 500 volts continuously without the temperature rise exceeding 35 degrees C. on any part except the commutator, and on that the temperature rise will not acceed 40 degrees C. The full-load continuous run may be followed by a two hour run at 7 500 amperes, 500 volts, at the end of which the corresponding temperature rises will not exceed 50 and 60 degrees C. These are the guaranteed figures which were met on test with a large margin. The efficiencies, including all measurable losses, are:—

Percent Load	50	75	100	125
Percent Efficiency	92.3	94.4	95.4	95.5

In this machine the peripheral velocity of the armature is approximately 9 400 feet per minute and of the commutator 5 500 feet per minute. The length of the commutator face is approximately 24 inches and, although the largest for the speed ever built, no difficulties were met in construction and no troubles have been experienced in operation. Figs. 4 and 5 show views of this installation, which, totalling 22 500 kilowatts, is the largest in the world of 60 cycle rotary converters. It is placed at the end of a 76 mile, 66 000 volt transmission line, which is subjected to some very severe atmospheric disturbances. Despite excessive swings of voltage and frequency, the rotary converters, unprotected by quick acting relays, have shown a surprising disposition to run through these storms without damage.

In some minds the question, in regard to the modern rotary converter, has been as to how will it act under abnormal pulsating conditions such as are likely to occur at the end of a transmission line during a storm. In regard to this the following is quoted from a letter written by the electrical engineer in charge of the installation shown in Figs. 4 and 5:—

"We naturally have to anticipate an occasional momentary fluctuation of voltage of more than 30 percent due to momentary short-circuits somewhere on the power company's distribution system. Any device which will throw the rotary converters out on an instantaneous voltage fluctuation of more than 30 percent would be apt to cause quite frequent interruptions which would be wholly unnecessary if such devices had, say, a one-second time limit. As a matter of fact, our people state that the rotary converters stay in and do not flash over with a momentary voltage drop of 50 percent."



FIGS. 4 AND 5—AN INSTALLATION OF WESTINGHOUSE ROTARY CONVERTERS
The largest installation of 60 cycle rotary converters in the world.

Some flashovers have indeed been experienced, under the worst conditions, but the resulting burning of direct-current brush holders and arms has been so slight that in every case the rotary converters have been made ready for service again in a very short time. In regard to this the engineer in charge of operation is quoted as follows:

"The alternating-current graphic curve-drawing voltmeter, connected on the low-tension side of the power transformers, registered voltage swings from 355 volts (normal, for six-phase double delta connection) to 600 volts, then down to 200 volts, then up again. It was during these high swings that the converters would 'flash over;' the low dips would give us very little trouble as we would manage to stay on the line, with only a little flashing—i.e.-shooting sparks, not amounting to a 'flash over.' "

These abnormal conditions during lightning storms will in time, undoubtedly, be largely eliminated by the power company, by suitable protective devices on the transmission line. In the interval they are providing opportunities for the apparatus connected to the line to give some instructive demonstra-

tions of its ruggedness. They exceed anything it was reasonable to contemplate as permissible for the satisfactory operation of synchronous apparatus; hence it is not surprising that at first it was thought it would be necessary to take immediate steps to provide the rotary converters with fairly sensitive low voltage and over-voltage relays. To again quote the same electrical engineer:—

"You must bear in mind, however, that occasional short-circuits on distribution systems are absolutely unavoidable and machines so sensitive that they will withstand no disturbance whatever are not commercially practicable. From the writer's observation of the behaviour of the machines and the reports received from our own people, we believe that these machines are in this respect much better able to take care of the conditions which obtain than you apparently believe."

There have been many reports such as these, with reference to the various operating characteristics of these 2 500 kilowatt, 400 r.p.m. rotary converters, all of which indicate that the attitude of mind of the manufacturer has been a conservative one. It has been a sincere belief in the advantages of high speed and a faithful endeavor to attract the attention of the public to them which has brought about these results, and not, as some at one time thought, a question of having, "gone wild over the subject of speed."

Equipment for Electric Arc Welding

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IN THE JOURNAL for January, 1914, some of the more important applications of arc welding were described. Little was said, however, regarding the apparatus required, and it is the purpose of this article to indicate the equipment found most satisfactory and to explain the method of operation.

THE QUESTION often arises as to what equipment is essential for the practice of arc welding. In the early days of the art, resort was made to various types and arrangements of apparatus, most of which was home made or else modified to suit the special conditions. For instance, water barrel rheostats formed a part of many early welding plants.

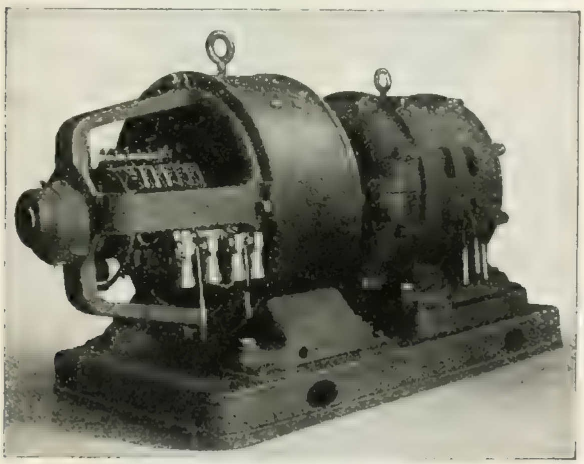

FIG. 1—TYPE OF MOTOR-GENERATOR SET USED IN ARC WELDING

The increasing use of arc welding in steel foundries, machine shops, electric and steam railway repair shops, ship yards and steel mills has produced a demand for welding outfits specially designed to meet the requirements of this interesting application of electric power.

A complete arc welding outfit should include:—

1—A low voltage, direct-current generator.
2—A switchboard for the control of the generator.
3—Outlet control panels for the various welding circuits.
  a—Combination carbon and metallic electrode welding.
  b—Metallic electrode welding only.
4—Electrode holders for carbon and metallic electrodes.
5—Protective coverings for the operator.
6—Welding materials, such as spare metallic and carbon electrodes, flux and filling material.

Molding blocks, fire clay, and preheating furnaces are sometimes required for special applications, but are not considered essential for average commercial work.

GENERATING EQUIPMENT

Arc welding is inherently a low voltage application of power, and although welding can be done from direct-current circuits of 110, 220 and 550 volts, this practice is extremely wasteful and should only be permitted when the saving to be made by arc welding is so great that the cost of power can be neglected. Direct-current generators delivering 75 volts or thereabouts are now in almost universal use to supply power for welding systems, and since practically all shops and mills are now operated by electric power, the usual practice is to install a motor-generator set. If electric power is not available, the welding generator can be driven by a steam or gasoline engine, either belted or direct-connected.

Welding generators should be compound-wound in practically all cases and should have commutating poles, on account of the heavy overloads incident to welding work. The amount of compounding for best results depends upon the service; in some cases flat compounding may be best, while in others it may be necessary to overcompound from three to four percent at full load. The latter amount is especially desirable with induction motor drive, on account of the drooping speed characteristic. A 600 ampere welding motor-generator driven by an alternating-current motor is shown in Fig. 1. The capa-

city of the motor-generator set is determined largely by the class of welding to be done and the number of operators working simultaneously. From the standpoint of heating, the rating of the machines is not of particular importance because welding is essentially an intermittent service. If the arc is used for cutting work, such as risers on steel castings, then the service may approach continuous operation, and allowance must be made for such conditions.

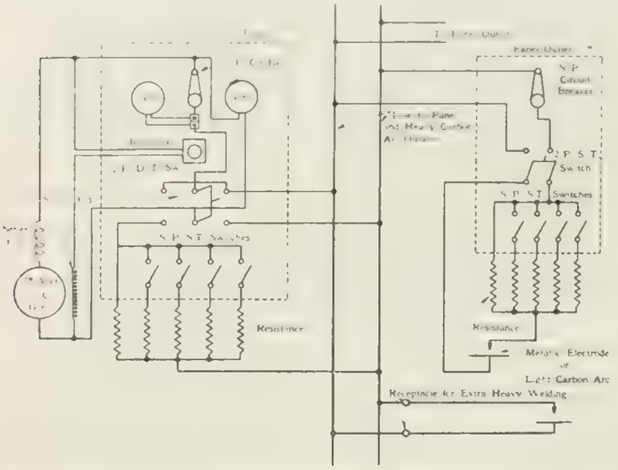

FIG. 2—SCHEMATIC DIAGRAM OF ARC WELDING ARRANGEMENT FOR GENERAL WORK

SWITCHBOARD AND CONTROL APPARATUS

Switchboard and control apparatus for arc welding has passed through a period of development, during which a number of schemes have been used to a greater or less extent. The first welding plants were one man outfits, so arranged that the welding was done in an enclosure adjacent to the generator supplying low voltage power. The application of arc welding, however, has grown to such an extent in several industries that it has been found convenient and profitable to expand the one man outfit into a system permitting a number of operators to work simultaneously at points scattered over a considerable territory. This development has been brought about largely by the increased use of the metallic electrode process, which has been adopted in steam railway and locomotive shops for many classes of work.

Until recently, most control schemes have used relays and contactor switches, and have generally been more or less complicated. The principle involved has been that of starting the arc through a high ohmic resistance, and after the arc is started, to remove or short-circuit a portion of this resistance. By so doing, it is claimed that the generator is protected from the heavy rush of current which normally ensues when the electrode is touched to the work to strike the arc. It has been found, however, that this rush of current is not large, rarely exceeding 160 percent of the normal welding current. Furthermore, with the advent of commutating-pole generators, the generating equipment has much better commutating characteristics, and it is now feasible to use a very simple system of control, eliminating all relays, contactors, etc.

In Fig. 2 is shown schematically an arrangement by which welding can be done either with the carbon electrode process, using current up to the full capacity of the generator from a single electrode, or with the metallic electrode process, in which case it is possible for several operators to work simultaneously without interference. When the double-throw switch shown on the generator panel is turned to the right, the generator feeds directly to a bus line. This bus line is connected to various panel outlets each one of which controls a welding circuit. Panel outlets, such as the one shown at the right in Fig. 2, can be installed at convenient points where it is desired to do welding. When the double-throw switch mentioned above is thrown to the left, current is supplied to the bus line as before, except that the adjustable resistance at the generator panel is connected in series with the line. It is now possible for the operator to do heavy carbon electrode welding at any point along the bus line, by simply connecting directly to the line. Receptacles and plugs make a convenient method of quick connection. It is necessary to regulate the current for a heavy carbon arc at the generator panel by means of the single-pole single-throw switches.

The general scheme of connections is the same in the generator panel and the outlet panel. The outlet panels, such as shown in Fig. 3, are designed for combined metallic and carbon electrode operation requiring up to 300 amperes for the carbon arc, and for the metallic electrode approximately 150 amperes

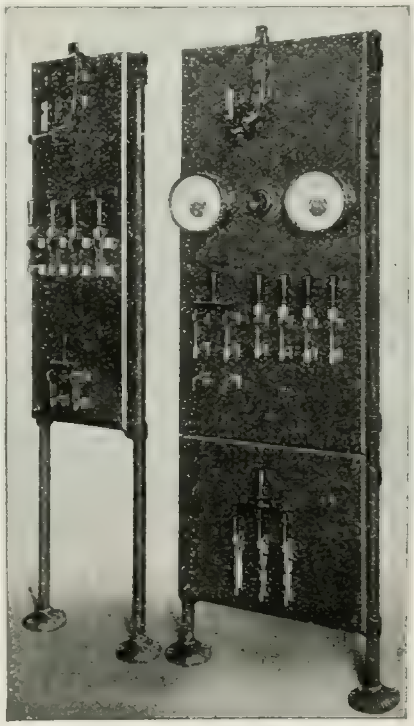

FIG. 3—SWITCHBOARD PANELS FOR ARC WELDING
Generator control panel on the right; outlet panel on the left.

ELECTRODE HOLDERS

There are two distinct types of electrode holders, as shown in Fig. 4. The carbon holder consists of an

aluminum rod, one end being provided with a suitable connection to the cable supplying current. On the other end of the rod a tube is welded, this tube serving as a receptacle for the jaws or clamps holding the electrode proper. The end adjacent to the cable is provided with an insulating and heat resisting handle and shield, so as to protect the operator's hand from the heat of the arc. This holder, while light enough to be handled easily, is strong mechanically and has ample carrying capacity for currents up to 500 amperes. The carbon electrode is a hard, solid carbon rod about six to eight inches long and one inch in diameter.

The metallic electrode process requires not over 150 amperes and hence the holder is of different design. The electrode material is also quite different, consisting of iron wire from one-eighth to one-fourth inch in diameter. The holder is lighter in design and the disc shield is omitted, since the arc is not so powerful as the carbon arcs. The clamp is arranged to hold electrodes of different sizes without adjustment.

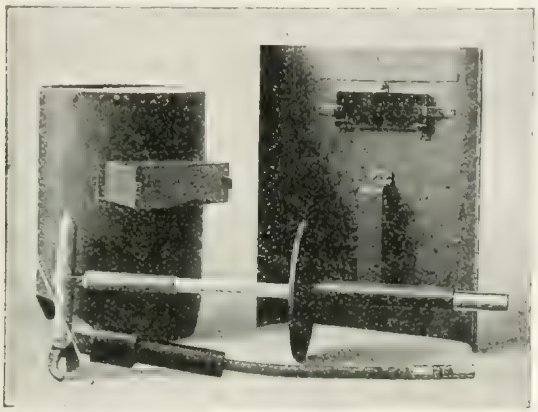

FIG. 4—PROTECTIVE APPARATUS FOR THE OPERATOR
Hood, shield and holders for both types of electrodes.

PROTECTIVE COVERINGS

As far as practicable, it is recommended that welding be done within an enclosure so as not to interfere with other work in the vicinity, and also for the protection of nearby workmen. The intense brightness of the arc requires also that the operator's head, hands and body be thoroughly protected. Simply shielding the eyes with a pair of colored glasses is not sufficient, as is the case in oxy-acetylene welding, since exposure to the ultra-violet rays of the arc produces a burning very similar to severe sunburn, which does not show at the time but manifests itself after ten or twelve hours. For the protection of the body, ordinary clothing is sufficient, while the hands and wrists should be covered with gauntletted gloves. For the protection of the head the best device is a hood, such as is shown to the left in Fig. 4. It consists of a cylinder of micarta fiber, suitably shaped at the bottom so as to rest easily on the shoulders. The support in front for the window holds the glass several inches from the operator's eyes. Hoods may also be arranged so that the glass window can be pushed up and back, so as to permit an unobstructed view of the work without removing the hood.

The really important part of the hood is the glass window. The iron arc is rich in ultra-violet rays, and it is against these rays that the eye must be protected. Recent scientific investigations of the subject seem to indicate that the best arrangement is to have three layers of glass, the outside thickness being of ordinary white glass simply for protection against the heat of the arc. If broken, it can easily be replaced at slight expense. The second layer should be of a greenish or amber tint and should be chosen with regard to its opacity to the ultra-violet rays.* The third layer should be of a neutral tint with sufficient density of color to reduce the brilliancy of the light of the arc to a comfortable degree.

For short welds a hand shield may be used, this being constructed of sheet steel, or aluminum, as shown to the right in Fig. 4. The hood is recommended for general use and must be used when filling in material is to be supplied to the weld.

WELDING MATERIALS

The principal materials used in arc welding are metallic electrodes, carbon electrodes, flux and filling material. The kind of metal used for metallic electrodes is most important; one of the best materials is soft Norway or Swedish iron in round rods about 12 inches long and from one-eighth to five sixteenth inch in diameter. Low-carbon steel wire has also given fair results in many cases.

The carbon electrodes are consumed slowly, but are subject to more or less breakage. Solid carbons without coring or graphite, especially manufactured for welding, can now be obtained from several manufacturers.

A very good flux for wrought and malleable iron and steel of all kinds consists of a mixture of 15 to 25 percent of red oxide of iron (Fe_2O_3) and 85 to 75 percent of borax ($Na_2Bo_4O_7$). The theory in connection with its use is that any carbon which may have been introduced into the weld from the carbon electrode, will unite with the oxygen in the flux to form carbon dioxide gas (CO_2) leaving pure iron as a residue. If, however, the gas should not be entirely eliminated, it will cause sponginess in the metal. The borax tends simply to prevent oxidation by excluding the air. In the use of borax as a flux, much better results will be obtained if the water of crystallization, of which it contains about 47 percent, is first removed. This can easily be accomplished by melting the borax in a crucible until it is free from all bubbles, then pouring it out, allowing it to cool and finally pulverizing it. Used in this way, it does not swell, makes a much better flux and helps to give a more perfect weld; for brass, zinc or lead welding, it is sufficient to use borax alone.

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*See a paper by M. Luckeish on "Glasses for Protecting the Eye in Industrial Processes" in the Transactions of the Illuminating Engineering Society, Vol. IX, No. 5, p. 472.

FILLING MATERIAL

Material of the same kind as the metal to be welded is generally used as a filler. For wrought iron and steel the filling material may be soft-iron rod, punched-iron scrap (boiler plate) or broken bits of steel castings; for cast and malleable iron, soft iron rod, punched-iron scrap, copper or special cast iron

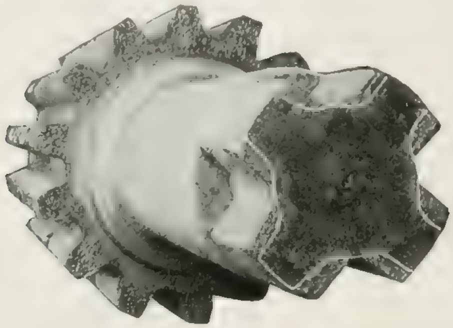

FIG. 5—A WORN BLOOMING MILL PINION REPAIRED BY THE ARC WELDING PROCESS

The white lines show the original outlines, the metal outside having been added. The cost of repairing four ends (two pinions) was $170.00. The pinions cost $1 000.00 apiece and could be saved by no other process.

high in silicon may be used; for brass, lead and zinc, rods or castings of the same material will do.

GENERAL INSTRUCTIONS IN THE ART OF WELDING

Welding by any process, except spot and butt welding by alternating current, is an art and like all arts is not subject to any definite rules. There are, however, certain fundamental principles which must be observed and, having observed these, the degree of success attained in the prosecution of the art will depend almost entirely upon the skill and intelligence of the operator. Some workmen pick up the art easily and in a very short time, while others experience great difficulty and never produce consistently good work. The operations may be divided into the preparation of the work; striking the arc; and manipulation of the electrode, filling material and the work being welded.

Preparation of the Work—One of the most important factors in producing good welds is the absolute freedom of the article to be welded from dirt, grease, scale and other foreign matter. A good stiff wire brush is very useful in cleaning the work, and chipping must often be resorted to in order to start with bright metal. A sand blast, if available, is also very useful to clean the work, especially where surfaces of considerable area must be gone over. It is practically impossible to produce good welds if the material is greasy or soaked with oil. Frequently the work can be cleaned quickly and easily by the arc itself, no attempt being made to weld. If the work is tilted the impurities can be melted and allowed to run off by gravity.

Having thoroughly cleaned the work, the next step is to prepare the spot to be welded by shaping it to receive the weld. If a crack in a plate or bar is to be repaired, it should be chipped out with cold chisel and hammer so that a V-shaped groove is formed. If a broken casting is to be repaired, temporary supports for the broken member may be necessary. A projection, such as a lug or lifting bail, may have to be built up, in which case it will be necessary to use molding blocks of iron or carbon; sometimes fire clay is used to form a temporary mould.

In some classes of work it is advisable and sometimes necessary to preheat the metal before welding. This is done to avoid cooling strains in the metal and to insure even contraction throughout the piece. A furnace for preheating is therefore required. Occasionally, for large work it may be necessary to construct a temporary furnace of ordinary fire brick about the piece with removable parts so that when the metal has reached a cherry red condition these parts can be opened, the electrode for welding inserted and the weld made.

Striking the Arc—The work, having been properly prepared, should be connected to one side of the welding circuit. If the piece is small, this is most conveniently accomplished by having an iron table on which to place the work, the table being permanently connected. Where the work is large the current conductor can be fastened on with a clamp, or simply hooked on without any clamping. The resistance is next adjusted and the circuit breaker and line switch closed in order, the operator with the electrode holder in his hand taking a position in front of the work. If the carbon electrode is used, filling material should be within easy reach. The operator then pulls the hood over his head, touches the electrode to the work, and instantly withdraws it, thus striking the arc. The carbon electrode should be withdrawn to a distance of two or more inches from the work. Little difficulty will be found in striking the carbon arc. With the

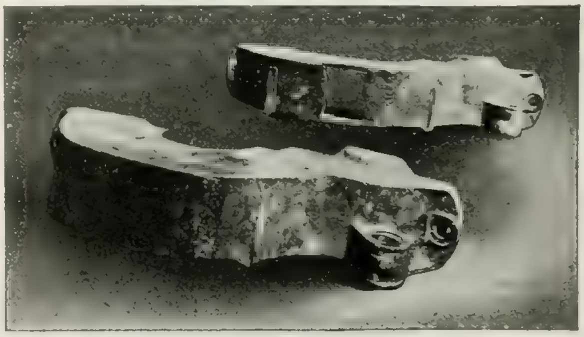

FIG. 6—VIEWS OF A WORN GEAR CASE (UPPER) AND A SIMILAR GEAR CASE WITH HOLE PATCHED BY ARC WELDING

metallic electrode, however, conditions are quite different. The electrode has a tendency to stick and will frquently "freeze" to the work. Furthermore, the arc is quite short; in fact, the metallic arc can seldom be operated longer than about three-sixteenths of an inch. The operator must feed the electrode down into the work at about the same rate as that at which it melts

off and the electrode must be held steady or the arc will be broken. A good plan for the beginner is to start with the carbon arc and, as skill is acquired, he can progress to the more difficult metallic arc process. It will often assist materially if the operator provides himself with a steady rest for his hand when using the metallic electrode.

Manipulation of Arc and Weld—After the arc is struck, it is allowed to play upon the piece, and if the carbon electrode is used it is given a rotary motion by the hand. With the metallic process, the electrode is at once both the heating element and the filling material and the arc is allowed to play on the exact spot where it is desired to deposit the metal to be welded. With the carbon electrode, when the metal boils, the flux, if any, is used and the filling material should be added, a little at a time, the arc of course being continued meanwhile until the metal is thoroughly melted and the weld made. As soon as the metal commences to cool it should be hammered thoroughly by hand or by power in order to prevent sponginess and to give the metal a finer grain. Hammering the weld also tends to work out any scale or slag which may have formed during the welding stage.

TABLE I—SAVINGS EFFECTED IN A RAILWAY SHOP.

Operation	Cost of Welding	Cost of Replacement or Repair by Other Methods
Welding tender draft casting	$ 1.11	$ 18.31*
Welding tender center draft casting	4.36	19.06*
Welding tender draft arm	1.11	19.08*
Plugging 51 holes in expansion plate, holes 1" dia. by 1½" deep	2.75	10.15
Repairing mud ring	6.50	34.57†
Building up flat spots on locomotive driver	.40	225.00**
Building up four piston valve flanges	9.52	24.20*
Repairing mud rings	5.57	32.70†
Plugging four holes 2" dia. by 4" thick	1.16	4.44
Cutting four 6" holes in tender deck sheets ½" thick	1.08	8.35
Plugging holes in two driving box cellars	.55	2.55
Welding eccentric strap, broken through neck	1.08	41.28*
Building up jaws of two pedestal caps	3.49	10.00
Welding one driving box for locomotive, broken through crown	5.75	39.31*
Welding frame stiffener on locomotive	3.29	14.73
Welding main rod broken through end	6.35	70.49*
Repairing fire box	134.89	869.58‡
Welding two spokes in trailer wheel center	7.72	68.05*
Welding two spokes in driving wheel center	7.98	99.98*
Welding three spokes in driving wheel center	11.20	126.60*
Welding two spokes in driving wheel center	5.13	112.09*
Welding cracks in bulk head in tender tank	2.33	8.00
Welding cracks in-side and door sheets of fire box	4.23	24.35†
Welding bridge in flue sheets	2.88	20.12†
Welding cracks in side sheets	26.15	31.79
Repairing air drum	2.83	12.64*
Welding guide yoke	1.68	16.15†

*New parts required. †Repair. **Estimated cost to turn down all drivers as would otherwise be required. This would mean also the loss of at least one year's wear on the tires. ‡New fire box required.

Overhead welding can be done without resorting to any special devices, such as magnetizable electrode holders, or coated electrodes. Success depends almost altogether on the skill of the operator, and not particularly upon other factors, such as amount of current, size of electrodes, etc. Welding in a vertical plane is comparatively easy. The acid test of expertness in arc welding is without question overhead work and good results indicate that the operator has qualified for any situation which may arise.

POLARITY

It is recommended in all cases that the electrodes be connected to the negative side of the circuit. There are several reasons why this is considered best for both metallic and carbon electrode welding. Experience has demonstrated that if the flow of current is from the weld to the electrode, and the arc is kept long, practically no trouble is encountered with hard welds which are difficult to machine. Therefore the electrodes should be negative. Furthermore, it is known that approximately 75 percent of the heat of the arc is at the positive pole and therefore at the weld where it is most needed, provided the electrode is of negative polarity. So far as the operation of the arc itself is concerned, it seems to make little difference whether the electrode be positive or negative.

CHOICE OF CARBON OR METALLIC ELECTRODES

If the weld is of considerable size and if strength is not of prime importance, the carbon electrode process in general will do a good job, and in a considerably shorter time than if the metallic electrode were used. The carbon electrode is always used for cutting; also it is applicable where it is not necessary that the heat be localized. Average carbon electrode welding requires from 300 to 400 amperes. Heavy cutting work, such as removing risers from steel castings, may require as much as 600 to 800 amperes.

The metallic electrode should be used where strength of the weld and localization of the heat are important. Also small welds are made better by this process. Average metallic electrode welding requires approximately 150 amperes. In welding thin sheets, or in other applications where the heating must be localized as much as possible, less current must be used. Good work in sheets down to one-sixteenth inch in thickness can be done with about 100 amperes, if the electrode is carefully manipulated.

SAVINGS MADE BY WELDING

There is no longer any question that large savings in time and money can be secured by electric arc welding, not only when used for repair work but as a regular manufacturing process. The greatest field of application is in the steam and electric railway repair shops. Through the courtesy of a large American steam road the figures of Table I were obtained. They were taken from actual jobs carried through the shop at various times and give the actual cost of welding compared with the cost of returning to service by any other method, whether by replacement or by repair of old parts. The arc welding costs were based on a power cost of 51 cents an hour for the carbon arc, and 17 cents an hour for the metal pencil arcs, together with the cost of labor and an overhead charge of 40 percent.

Control Operation on the New York Railways

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THE RAILWAY NUMBER of the Journal for 1913, contained a full description of the "PK" control, as to its mechanical arrangement and electric circuits, and also a brief enumeration of its advantageous features. The article also referred to the adoption of this type of control for use on the New York Railways stepless cars.

THE NEW YORK Railways stepless cars to the number of one hundred seventy-five have been placed in operation in the Broadway Service, the last cars going into service about six months ago. The control for these cars is of the "PK" type and was originally designed to meet the requirements of multiple-unit operation. While the service has been limited to single-car operation and may continue so, yet the efficiency and reliability of the equipment, together with the conspicuous demonstration of its other advantages, indicate the advantage of using this type of control, even if multiple-unit operation should not further be contemplated. The automatic acceleration feature has proven a very desirable one, and has been adhered to for all characters of service although, if for any reason it had been considered advisable, the current limit device might easily have been cut out entirely or, by a simple adjustment, made to serve merely as an additional excess overload limit. Non-automatic acceleration depending upon the notch-by-notch movement of the master controller handle could thus be secured.

FIG. 1—STEPLESS CARS OF THE NEW YORK RAILWAYS COMPANY
At 34th St. and Broadway, the busiest crossing in New York City.

The equipments, as operated, have the advantage of the fixed limit to motor current input and to rate of acceleration which may be adjusted as near to the slipping point of the wheels as desired; yet they are equally as flexible as the hand control in that the acceleration may, at the will of the motorman, be graduated to as slow a rate as deemed necessary; for in no case will the main drum move beyond the point indicated by the master controller handle. The same number of operating notches are thus available as on the standard "K" controller for regulating the speed to the requirements of street traffic. Normally, in starting from rest the master controller handle is turned to the full parallel position almost immediately after the car comes to a full stop. When the car door is closed the controller circuit is established and the car starts and speeds up automatically.

The dead man's emergency attachment is considered a very good feature if for no other reason than that the motorman is thereby enabled to make a quicker emergency stop by simply releasing the controller handle in case collision with pedestrians is imminent. The facility with which this device may be operated was a source of a little trouble at the start, when the motormen were being broken in. While it is very easy indeed to manipulate the master controller, carelessness would result in setting the emergency brakes, dropping the fenders and applying sand to the tracks. Except for cautions about holding the controller handle properly and not releasing it until the reverse handle was thrown to center, very few instructions to motormen were necessary.

As already stated, the stepless cars were assigned to the Broadway division, which is unquestionably the hardest street car service in this country as far as the control is concerned. Heavy traffic, more frequent passenger stops—possibly twenty to the mile—fire and crossing stops and interruptions from the worst possible congestion of vehicular traffic, combine to produce in a day's run an enormous number of control operations.

The stepless cars are inspected according to the same mileage basis as the standard "K" control equipments, brake shoe adjustment and truck inspection being the determining factors. There is very little wear and tear on the auxiliary aparatus, such as master controllers and relays, and these parts require merely routine inspection. Since all of the motor current is broken on the line switches there is very little burning of the main control contacts, this burning being about one-half as much as on the corresponding contacts with the standard "K" controller arrangement

with double-end operation and about one quarter as much as where single-end "K" control is used. The burning on the other contacts is so slight that they should last for years without renewal. Automatic acceleration undoubtedly aids somewhat in reducing

FIG. 2—CAR OF THE UNION RAILWAY COMPANY

At the busiest intersection in the Bronx, 149th St. and Third Ave.

the burning. Since there is so little arcing on the main drum the necessity for removing the controllers from cars for overhauling is practically eliminated. An inspection of the "PK" operating heads on several of the cars, after nearly one year's service, does not show any appreciable wear on the operating mechanism and indicates that these parts should last for a long time without having to be overhauled.

While this equipment possesses all the general advantages of remote control and the advantage that multiple-unit operation and automatic acceleration are permissible, and that such safety devices as the dead

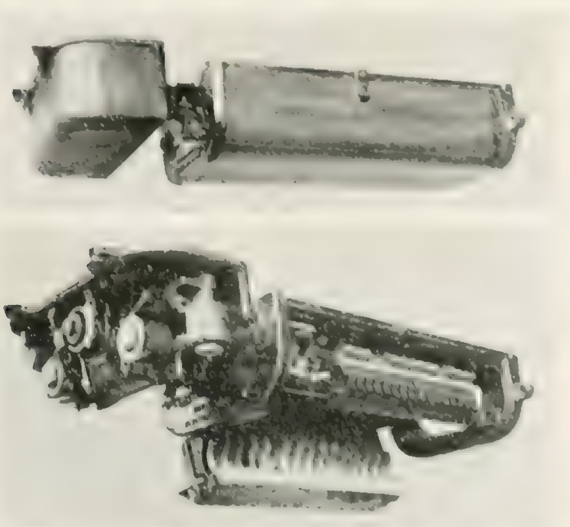

FIG. 3—PK CONTROL AS MOUNTED UNDER THE CARS

man's emergency door, interlocking, etc., are available, it has nevertheless been very clearly demonstrated that the control can be maintained fully as cheaply as the standard "K' arangement. During the past winter the equipments were subjected to the worst weather conditions which New York City has experienced for a great number of years, when several days of weather below zero were followed by severe snow storms. The reliability of operation was not in the least affected by the extreme cold and has not been affected by any other weather conditions.

On the New York Railways cars, the main controller is located in the motorman's cab on one end and stands in a vertical position. However, the position and location of controller are apparently matters of indifference. On the Third Avenue Railway the controller is mounted under the car body in a horizontal position. One "PK" equipment has been in service on this road for about one year and, by means of a special lubricating attachment, was operated for four months without even having its contacts touched.

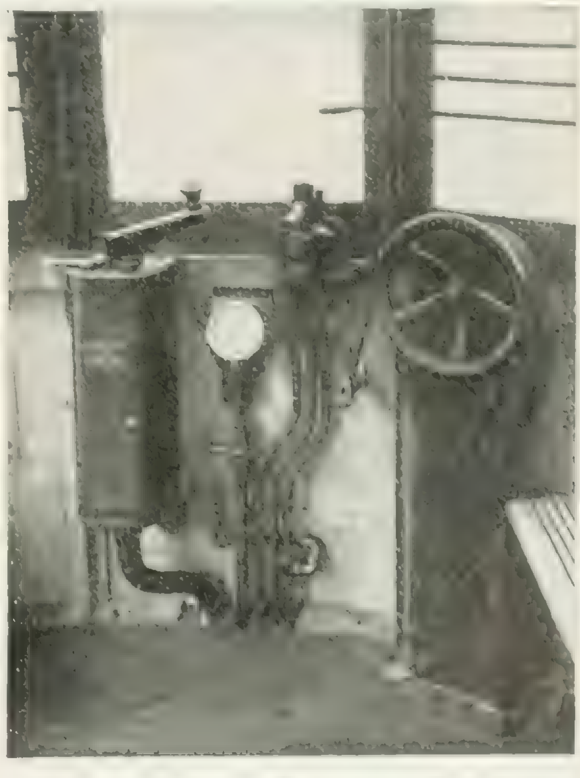

FIG. 4—GENERAL VIEW OF MASTER CONTROLLER

Forty-nine additional equipments are now being installed for the Third Avenue Railway Company on the new 24 inch wheel stepless cars. The "PK" control was chosen as the best suited for their purposes after exhaustive tests on a trial equipment, extending over a period of several months. It was desired, both on account of space economy and in order to insure perfect safety to passengers, to exclude all main power control apparatus from the platforms, especially since on this type of car the platforms are virtually part of the car interior. The "PK" equipment provided the required remote control and, in addition to being the most suitable on account of space limitations underneath the car, it provided for both hand and automatic acceleration; it was also considered that it would prove most economical. For twenty-four of these cars

the Third Avenue Railway Company is using their old surplus controllers, and are themselves mounting the operating heads on the controllers. The "PK" heads can be applied to any of the standard type "K" controllers at purely nominal expense. Old and partially worn controllers are practically as good as brand new ones for this purpose.

For the railroad man who is considering the question of revamping his old equipments in order to get remote control, automatic acceleration or dead man's emergency, or of converting some or all of his equipments for multiple-unit operation, the range of possibilities due to the development of the "PK" control is a wide one. To say the least, a very interesting field has been opened up, which possibly has been the dream of some of our car equipment engineers for a long time past. It should prove interesting to watch the results.

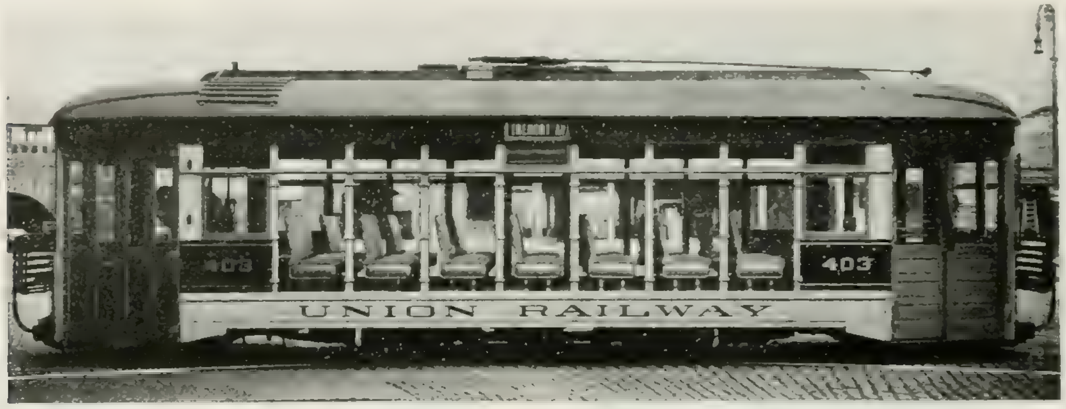

FIG. 5—ONE OF THE UNION RAILWAY COMPANY'S SEMI-CONVERTIBLE STEPLESS CARS

Standardization of Electric Locomotives

G. H. F. HOLY

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THE electric locomotive was introduced in the United States on steam trunk lines to assist the operating companies in congested terminals and where a dense passenger traffic existed. New fields of electric locomotive application have been presented in the last fifteen years, which had apparently at first not been considered. Large interurban systems have found it advantageous to provide an express service, which is handled by express cars with the same equipment as used on passenger cars, a change in the gear ratio of the motors being sometimes found necessary. This development was quickly followed by an express car hauling a trailer car. A complete freight service was next inaugurated and operated at night, thus permitting the use of the station and sub-station equipments for haulage of heavy loads without additional units and with a traffic secured that permitted an additional return on the capital invested. The freight service was not limited to any particular class or product or to that hauled by steam trunk lines. In many cases a day and night freight and passenger service is now maintained. In addition to the freight service, many electric trunk line roads and interurban systems handled some of their passenger service with electric locomotives.

G. H. F. HOLY

To meet the initial demand, the first electric locomotives were built to meet special limitations imposed by the operating companies and in some instances incorporated features and details which were standard for that particular system as applied to their motor cars, but which were not applicable to locomotive service. This involved the complete layout and design of the locomotive in each particular case, imposing a hardship not only on the manufacturer, but also on the purchaser. Such new designs required extra engineering cost, and extra cost in production. In case spare parts were later required they had to be specially made, since a standard stock was not available.

To meet the demands of trunk line electrification and of the interurban systems for electric locomotives to operate on 600 volts direct-current, a standard line of locomotives has been developed by the Westinghouse Company. This will eliminate unnecessary special features, extra cost and increased time re-

quired in production. A uniform type of locomotive has been obtained, making possible a minimum number of parts to carry as spares. The spare parts are readily available since the manufacturer can carry these in his supply department as staple articles. Although this development was made to apply on 600 volt direct-current systems, the same general types of locomotives, motors and equipment have been applied on higher voltage direct-current and single-phase systems.

FIG. 2—CLASS B LOCOMOTIVE

FIG. 1—CLASS A LOCOMOTIVE

The standard locomotives have been arranged according to weight and capacity, for service ranging from 25 to 65 tons and with motors from 35 to 225 horse-power each on the one-hour rating with normal voltage and natural ventilation. For convenience, locomotives from 25 to 30 tons are designated as class *A*, and 35 to 50, 44 to 50, and 50 to 65 tons as classes *B, C* and *D* respectively. Table I indicates the locomotive characteristics for the several classes under varying motor ratings and locomotive weights.

FIG. 3—CLASS C LOCOMOTIVE

The class *A* locomotives, as illustrated by Fig. 1 are for light switching, work trains, light express service, and in districts where snow conditions must be overcome, they can be used as snow plows. These locomotives were also designed to be especially adapted to conditions where clearances are at a minimum and curves are very sharp, as is shown by the dimensions given in Table II.

The class *B* locomotives, as illustrated by Fig. 2, are adaptable to similar but heavier service than the class *A* and have been applied to the class of service required by industrial and smelting plants.

Class *C* and *D* locomotives, used for heavy switching, freight and passenger service, are illustrated by Figs. 3 and 4. The same equipments are used on both classes of locomotives, the only difference being in the increased weight of the class *D* locomotives over that of the class *C*. The heavier locomotive is used where heavier trains are moved or where grades are an important factor. The additional weight in the heavier locomotives of each class is obtained, first by the increased weight of electrical equipment, and second by increasing the size of the various sections of the locomotive, adding increased strength.

FIG. 4—CLASS D LOCOMOTIVE

The standardization has been made on locomotives up to 65 tons, but units of larger size have been

built on the same general lines. The weights adopted have been considered best to meet the limitations of right of way, especially on the interurban systems. When larger units are required, and increased axle loadings on the right of way are not permissible, the desired result can be obtained by multiple unit operation of two or more standard locomotives.

The cardinal features of these locomotives consist of mechanical parts, (running gear and cab for housing equipment); motors; controlling devices for the motors; equipment details; safety devices (braking, sanding and signaling); and auxiliary apparatus that can be applied to improve the motor rating over natural ventilation. Each distinctive feature was studied and developed by the manufacturer working in conjunction with operating engineers to produce efficient, simple, compact and accessible locomotives, which would give a maximum service with minimum attention. The number of parts, especially those parts where wear must occur, has been reduced to a minimum.

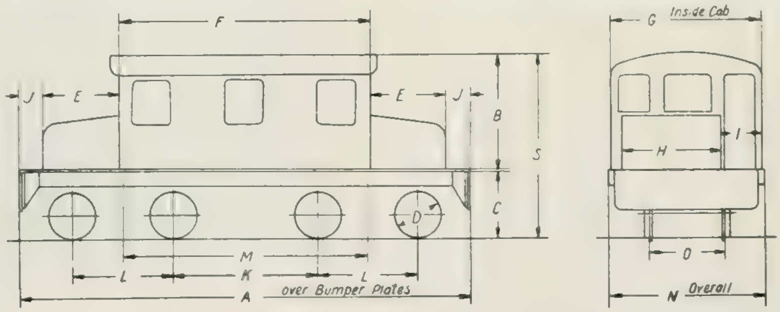
The running gear consists of two swivel equalized trucks with rigid bolsters on which the cab for housing the equipment is mounted. The standard truck shown in Figs. 5 and 6 has been developed especially for locomotive service. Swing bolster trucks designed for locomotive service can be applied, but they have been considered as generally unnecessary for this service. Arrangement has also been made for articulated trucks when the service requirements are such that these are demanded. The recommended truck shown in Fig. 5 has more than fulfilled the requirements imposed on locomotives that are now in service. This being the case, it has been considered unneces-

TABLE I—PERFORMANCE OF STANDARD BALDWIN-WESTINGHOUSE LOCOMOTIVES WITH MAXIMUM GEAR REDUCTION QUADRUPLE EQUIPMENTS

Locomotive Weight Tons			Motor Characteristics			Lbs. Tractive Effort One Hour Rating*	Miles per Hour One Hour Rating	Lbs. Tractive Effort Cont Rating*	Miles per Hour Cont Rating*	PERFORMANCE OF NORMAL WEIGHT LOCOMOTIVE — Approx. Max. Number of 45-Ton Cars That Can Be Handled									
										One Hour Rating					Continuous Rating				
										Straight Level Track	Percent Grades				Straight Level Track	Percent Grades			
Min	Max	Normal	Frame	Horse Power Single Motor	Volts						0.5	1	2	3		0.5	1	2	3
									CLASS A										
25	25	25	Split	40	500	5360	11	1960	15.4	16	6	4	2	1	5	2	1	....	...
25	25	25	Split	50	600	5520	13.4	1800	19.6	16	6	4	2	1	4	2	1		.
25	25	25	Split	60	600	5920	15.3	1800	22.5	17	7	4	2	1	5	2	1	.	
27	28	27	Box	75	600	7600	14.8	2160	13.8	23	9	5	3	2	6	2	1	...	.
27	28	27	Split	60	500	7800	11.3	2300	16.7	23	9	5	3	2	6	2	1		.....
27	27	27	Box	90	600	8000	16.8	1780	18.2	24	9	6	3	2	4	1	1		..
27	29	27	Split	90	600	8160	16.7	2100	26	25	10	6	3	2	5	2	1	.	.....
27	29	27	Split	75	600	8400	13.3	2200	21	25	10	6	3	2	6	2	1	......	...
25	30	25	Split	35	500	8620	6.2	3000	8.7	26	10	6	3	2	8	3	2	1	....
									CLASS B										
35	35	35	Box	95	600	10040	14.0	2160	15.8	30	12	7	4	2	[illegible]	2	1	..	
38	45	38	Box	140	600	12400	17.0	3400	25.5	38	15	9	[illegible]	3	9	3	2	1	
41	46	41	Box	175	600	13200	20.0	4000	28	40	16	9	5	3	11	4	2	1	
39	50	45	Box	100	600	18000	8.6	4120	13.6	55	22	13	7	5	11	4	2	1	..
									CLASS C										
44	50	50	Box	165	600	16400	15	5280	21.7	50	20	12	7	4	14	5	3	1	.
44	50	50	Box	225	600	19000	17.7	5300	26	58	23	14	8	5	15	5	3	1	.....
44	50	50	Box	120	600	21600	8.2	6200	12.7	66	27	16	9	6	17	6	3	1	1
									CLASS D										
51	56	52	Box	165	600	16400	15	5280	21.7	50	20	12	7	4	14	5	3	1	
51	64	52	Box	225	600	19060	17.7	5300	26	58	23	14	8	5	15	5	3	1	
49	65	56	Box	120	600	21600	8.6	6200	12.7	66	27	16	9	6	17	6	3	1	1

*All ratings are based on natural ventilation and the continuous tractive effort at 400 volts. The speed in miles per hour is based on the one-hour rated voltage.

TABLE II—DIMENSIONS OF STANDARD BALDWIN-WESTINGHOUSE LOCOMOTIVES



Locomotive	A Plate End Frame	A Cast End Frame	B	C	D	E	F	G	H	I	J	K	L	M	N	O	S
Class A	25'-8"	27'-4½"	7'-1"	4'-1½" 4'-2½" 4'-3½"	33" 34" 36"	3'-5½"	14'-0"	8'-9"	6'-0"	2'-5½"	2'-4½"	7'-0"	6'-0"	13'-0"	9'-0"	4'-8½"	11'-6" 11'-6½" 11'-7½"
Class B	—	[illegible]-2½"	7'-6"	4'-4" 4'-4½" 4'-5½" 4'-6½"	33" 34" 36" 37¼"	5'-0"	16'-6"	9'-9"	6'-6"	2'-7½"	1'-6"	9'-6"	6'-6"	16'-0"	10'-0"	4'-8½"	11'-10½" 11'-11" 12'-0" 12'-0½"
Class C and D	[illegible]	[illegible]	7'-[illegible]	4'-6" 4'-6½" 4'-9"	36" 37" 42"	5'-0"	18'-0"	9'-9"	6'-6"	2'-7½"	2'-4"	10'-4"	7'-4"	17'-8"	10'-0"	4'-8½"	12'-0½" 12'-1" 12'-3½"

sary except under extreme conditions to burden the standard locomotives with such special features as swing bolster trucks or articulated trucks, each requiring added stock in the storeroom and extra parts

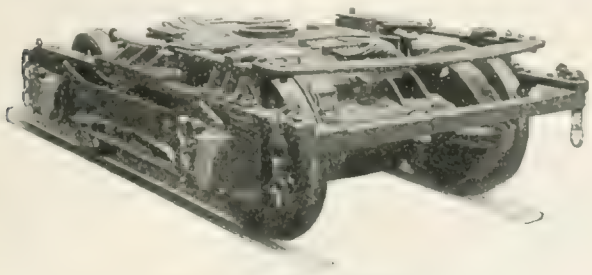


FIG. 5—STANDARD TRUCK

to come under the care of the maintenance department. Special attention was given to the design of the center pins to handle the tractive efforts and buffing strains that would be imposed. The driving journals and boxes are MCB size and type, and the wheels are forged steel with MCB tread and flange. The truck is also adapted to wheels with cast iron centers and shrunk or bolted tires with either MCB or A.E.R.A. tread and flange. All parts of the truck have been made to conform to MCB types and sizes, where possible.

The cab under-framing consists of center and side sills of standard rolled channel sections. The end repairs on account of end frame failures. Standard MCB automatic couplers are provided on all locomotives and mounted in a bumper pocket casting at each end of the locomotive. Provision can be made for the application of radial drawbar or friction draft gear when the service demands these parts.

The main cab used for housing the equipment and for providing operating stations is constructed of steel and provided with wood flooring. The windows are so located as to give a clear view of the track and to provide ample illumination of the interior. Arrangements have been made to provide a cab of wood if desired, when local conditions will permit and no fire risk is involved.

Table I shows that a sufficient number of motors are available to enable the selection of a locomotive that will be adaptable to all classes of service. Standard locomotive motors have been provided for high speed freight and passenger traffic. Special attention also has been given to the design of a slow-speed motor, Fig. 7, which gives a high tractive effort with relatively low power consumption, as shown in Table I, so that the interurban road of moderate size station equipment can, with the slow-speed motors, handle its freight traffic without installing additional station apparatus or line copper. The slow-speed motor is further available for switching service. The ratings given

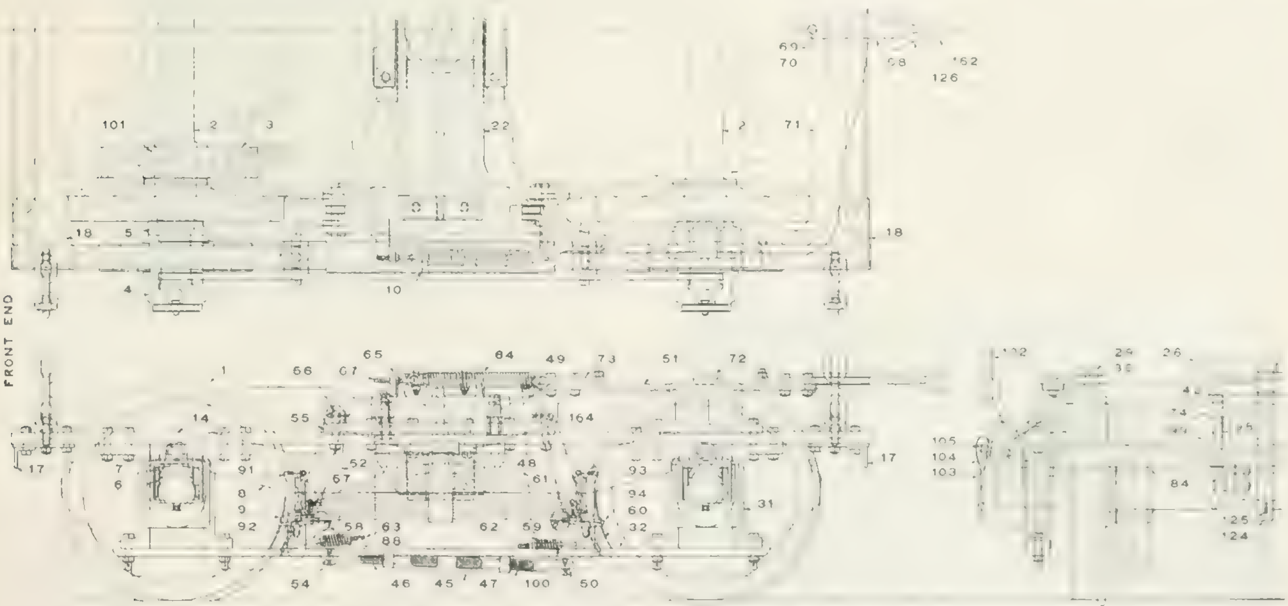


FIG. 6—KEY DRAWING OF STANDARD TRUCK

1—Wheel; 2—Axle; 3—Gear; 4—Journal Box; 5—Journal Box Dust Guard; 6—Journal Bearing; 7—Journal Bearing Wedge; 8—Equalizing Beam; 9—Equalizing Beam Spring; 10—Equalizing Beam Spring Seat; 14—Frame; 17—End Frame; 18—End Frame Gusset; 22—Transom; 26—Body Center Plate; 29—Side Bearing Plate; 30—Side Bearing Shoe; 31—[illegible]; 3[illegible]—[illegible] Cap; 42—Motor Suspension Bolt; 45—Brake Rod Turnbuckle; 46—Brake Rod Right Hand Thread; 47—Brake Rod Left Hand Thread; 48—Brake Live Lever; 49—Brake Live Lever Pin (Top); 50—Brake Live Lever Pin (Bottom); 51—Brake Live Lever Rod; 52—Brake Dead Lever; 54—Brake Dead Lever Pin (Bottom); 55—Brake Hangers; 56—Brake Hanger Pin (Top); 57—Brake Hanger Pin (Bottom); 58—Brake Head; 59—Brake Head Pin; 60—Brake Shoe; 61—Brake Shoe Key; 62—Brake Shoe Adjusting Spring; 63—Brake Shoe Spring Rod; 64—Brake Release Spring; 65—Brake Release Spring Fulcrum; 67—Brake Release Spring Adjusting Rod; 68—Brake Pull Rod Jaw; 69—Brake Pull Rod Roller; 70—Brake Pull Rod Roller Pin; 71—Brake Beam (Radial); 72—Brake Beam Guide; 73—Brake Live Lever Rod Jaw; 74—Motor Suspension Strap; 84—Motor Suspension Bracket; 88—Brake Shoe Adjusting Spring Seat; 91—Equal Beam Spring Link; 92—Equal Beam Spring Link Key; 93—Equal Beam Spring Link Pin; 94—Equal Beam Spring End Clip; 98—Motor Suspension Filling Piece; 99—Motor Nose Support; 100—Brake Shoe Adjusting Spring Eye Bolt; 101—Gear Key; 102—Safety Chain & Eye Bolt; 103—Journal Box Lid; 104—Journal Box Lid Spring; 105—Journal Box Lid Bolt; 124—King Pin; 125—King Pin Split Key; 126—Brake Connecting Link; 162—Brake Lever Clevis; 164—Brake Hanger Pin (Top) Live Lever End.

frames of the cab under-framing are of the all metal type, no wood end frames being used, it being considered that in case of collision with rolling stock, the locomotive should not be put out of service for in Table I can all be increased by forced ventilation, that is by providing the locomotive with a motor-driven centrifugal blower. The blowers force the air through a conduit built in the locomotive frame be-

tween the center sills whence it passes to the main motors through flexible connections. The use of the forced ventilation increases the continuous current capacity of the locomotive from 25 to 50 percent.

On the class *A* locomotives, the majority of the motors are split type with bar suspension similar to

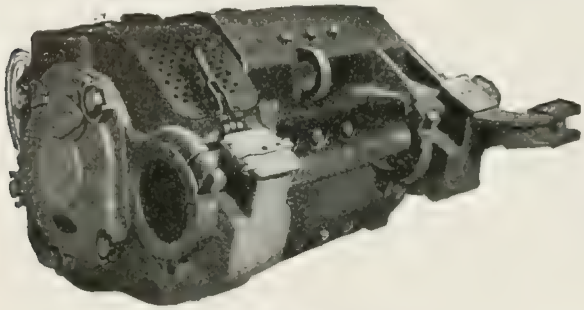


FIG. 7—SLOW-SPEED MOTOR

street railway mounting. The motors on classes *B*, *C* and *D* are nose suspended on the truck bolster and are of the box type frame.

The motor torque is transmitted to the driving axle through a pinion and gear as in street railway practice and the standard locomotives are equipped with solid forged steel gears and pinions of high grade. Provision has been made to supply the split gear when required on class *A* locomotives, but solid gears without keys are always strongly recommended.

After having eminently fulfilled all requirements in street railway and interurban service, the electro-pneumatic unit-switch (HL) control has been adopted for locomotive service and arranged for double end operation. The motors are connected permanently two in parallel and the pairs are connected in series and in parallel, with the necessary resistance in the circuit to produce smooth acceleration. The resistor con-

FIGS. 8 AND 9—ARRANGEMENT OF CONTROL APPARATUS INSIDE THE CAB

Fig. 8 shows the operating condition. In Fig. 9 the protective screen is removed.

sists of the cast iron type with three-point suspension. All equipments on class *A* locomotives, except the 90 horse-power split-frame motor, are provided with a control which gives a total of five notches in series and four in parallel. Classes *B*, *C* and *D* locomotives and the class *A* locomotive with the 90 horse-power split-frame motor are provided with a control which gives a total of nine notches in series and seven in parallel.

The control equipment is mounted in the main cab in such a way that each part will operate to the best advantage to give accessibility and compactness. The switch groups are located so that they will be accessible from all sides and so that replacements can be made without working in a cramped position, as shown in Figs. 8 and 9. The resistors are located above the switch groups, providing direct wiring connections and insuring an easy outlet for the heated air, which rises from the resistors through ventilators located on the locomotive roof. The reversers and series parallel switches are mounted under the switch group and are centrally located with respect to the motors. The apparatus in the central cab occupying the space under the resistors is enclosed by grounded expanded metal screens which are made up in sufficiently small sections to be readily removed for

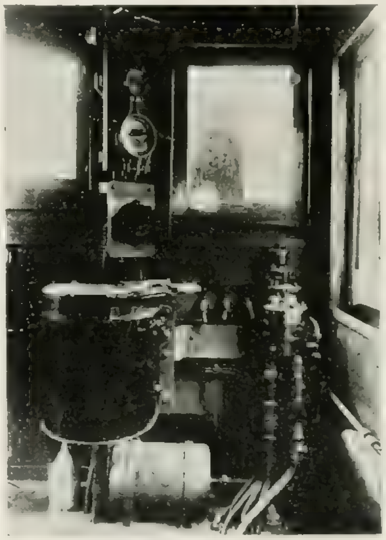


FIG. 10—OPERATOR'S STATION

inspection of the apparatus. A side elevation and plan view of a standard locomotive with the arrangement of control and apparatus indicated are shown in Fig. 11.

An operators station is located at each end of the main or central cab so as to provide a clear and unobstructed view of the track, as shown in Fig. 10. Sand boxes are provided in the hoods at each end of the locomotive, where they can be filled without entering the cab. They are arranged for pneumatic operation, the valves being located at the operator's station along with the master controller and engineer's valve for operating the brake. The compressor motors for the air brake equipment are mounted in the hoods at each end of the locomotive, this location being considered desirable in order to minimize noise in the cab which might distract the operator when receiving orders or signals. On the class *A* locomotive one compressor with a displacement capacity of 35

cubic feet of free air per minute is generally supplied. On the other locomotives, two compressors of the same capacity are supplied for normal service. The compressor equipment is investigated for each application and the standard as outlined is subject to change when special service conditions are imposed.

all necessary apparatus for the operation of the locomotive and train brakes. Arrangements have been made for the application of slack adjusters, signal equipments, governors, main reservoir and train line connections, when required. Hand brakes are applied as a part of the standard equipment.

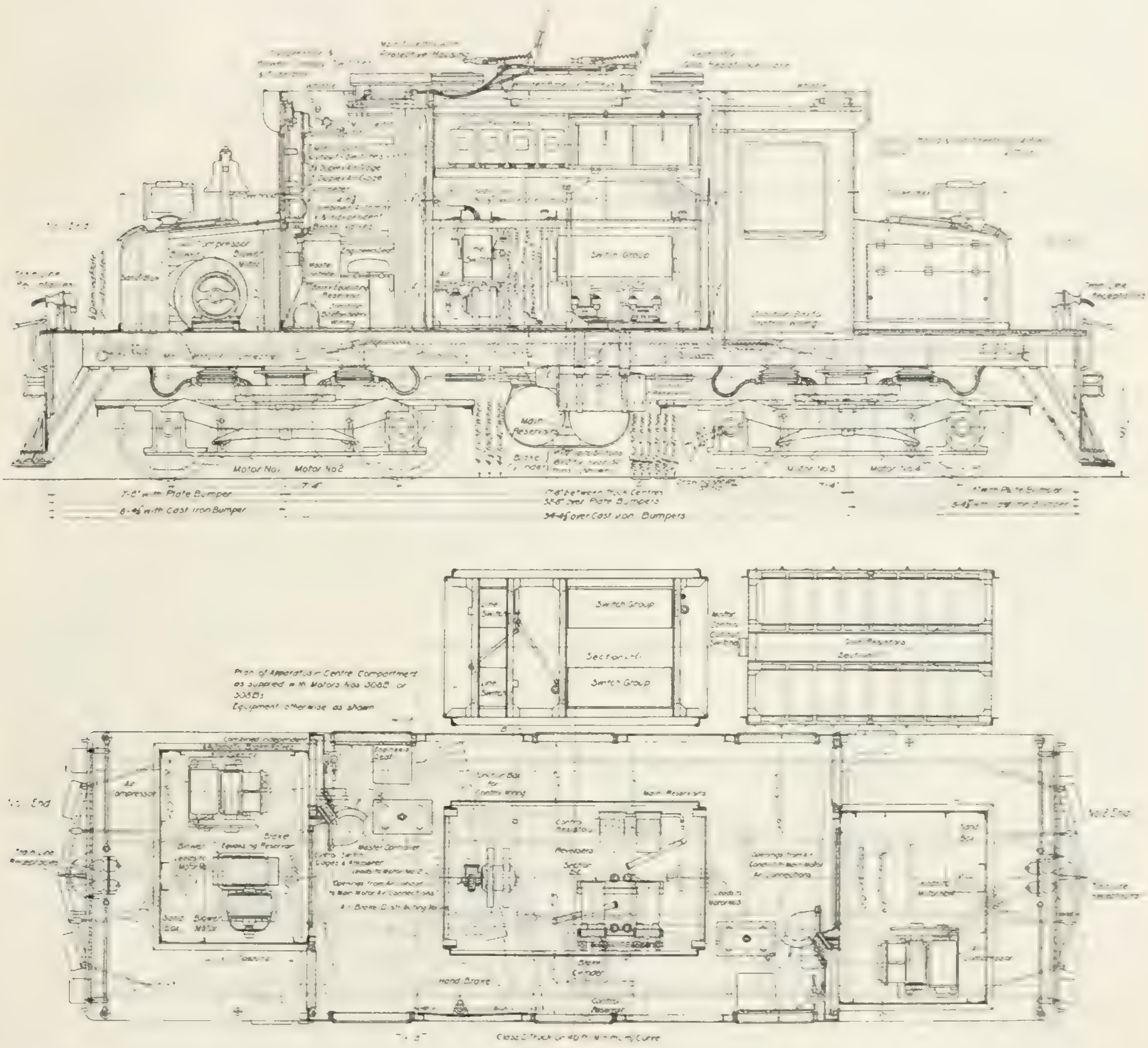


FIG. 11—PLAN AND ELEVATION OF STANDARD CLASS C AND D LOCOMOTIVES

Automatic and straight Westinghouse air brake equipments are applied on all locomotives. The equipment is similar to that applied on steam roads with the exception that the operation of the governor controls the electric motor-driven air compressor instead of a steam-operated pump. The brake equipment comprises

When the great number of combinations possible between the various motors available and the different weights of standard locomotives is considered, it will be seen that a standard locomotive may be selected which will meet any usual service cycle or right of way conditions.

The Selection of Correct Car Equipment

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THE IDEAL electric car equipment for any application is that equipment which will insure maximum safety, maximum reliability and maximum economy. Such an equipment comprises motors, control apparatus and current collectors, all of which should be ideal in design and construction to the extent that present knowledge, materials, costs and manufacturing facilities permit. Such an equipment also comprises apparatus which individually and collectively meets the following requirements:—

Mechanical ruggedness.
Elimination of useless weight.
Accessibility for inspection and repairs.
Insulation capable of withstanding high temperature, dirt and vibration.
Adequate creepage surface and flashing distances between live parts and ground.
Covers held securely against vibration and yet easily removed.
Ability to stand heavy overloads for limited periods.
Balanced design and construction so that when operated within its service capacity, long life and low maintenance will result and weakness will not develop in any part.

Of course, no apparatus is absolutely perfect. Therefore, the requirements given for ideal apparatus are those which experience so far has shown are essential and can be secured. These are enumerated for the benefit of those who are entering the field of electric railways but are already well known by the seasoned railway man. In addition to the above requirements, which are common to all apparatus composing an equipment, the ideal modern railway motor possesses the following features and qualities:—

Oil and waste lubrication of armature and axle bearings, with gauge chamber.
Material and size of bearings such as to secure maximum life and minimum risk of injuring other parts.
Means for preventing oil from armature bearings getting into the motor.
Sufficient clearance between armature and poles to allow for reasonable bearing wear.
Cross-bar and nose suspension for small and large motors respectively.
Safety lugs on suspension side.
Gears treated to secure uniform wear and to minimize breakage and wear.
Gear case material and supports such as to minimize breakage.
Housings secured to prevent turning and minimize wear.
Axle caps arranged to relieve axle cap bolts from carrying frame weight.
Axle brasses held securely.
Axle dust guards.
Commutators mica-insulated, under-cut and constructed to prevent high bars and grounding between bars.
Field coils strap-wound and held to prevent vibration and looseness from shrinkage.
Laminated pole pieces and armature core.
Armatures securely banded to prevent vibration of coils and to permit high speed down grades.
Armature coil supports at ends of core.
Insulation reinforced at ends of armature slots to prevent chafing and grounding.
Form wound coils designed to facilitate repairs and assembly.
Brush holders to permit radial adjustment and permanent uniform brush tension.
Brush size and quality to secure long life of brushes and commutator.
Wiring around frame securely held against vibration.
Tapped drain holes in bottom of frame.
Freedom from flashing.
Perfect commutation.
High efficiency.

The corresponding additional features and qualities essential to the ideal modern railway control are:—

Simplicity of apparatus and circuits.
Ease of installation.
Effective, non-destructive breaking of circuits in normal operation.
Ample protection against too heavy overloads, grounds, short circuits, surges in the contact line, and lightning.
Removal of circuit breaking parts from car platform, or complete remote control.
Sure operation.
Prevention of false operation.
Smooth acceleration.
Minimum number of steps consistent with smooth acceleration.
Minimum losses.
Service capacity equal to that of the motors to be controlled.

Other features of an ideal control which are not applicable in all cases but are essential in certain instances are as follows:—

Train operation.
Automatic acceleration.
Automatic emergency braking when controller handle is released suddenly.
Emergency braking by mechanically reversing motor connections when both air and power fail.

In addition to the common requirements enumerated, the ideal modern railway current collector has the following features and qualities:—

Light weight of moving parts.
Flexibility in operation.
Wearing parts quickly renewable.
Operation with minimum wear of the conductor.
Sparkless collection of current.

Assuming that a line of motors, control apparatus and collectors which meets these requirements is available, the problem of securing an ideal car equipment for a specific service then becomes one of selecting the correct equipment. The motors, control apparatus and collectors may individually meet the requirements of idealism as outlined in the preceding paragraphs, and yet the car equipment as a whole, because of misapplication, may fall far short of being the best. From the standpoint of application, equipments may be divided into three classes with respect to capacity, namely, those which are:—1—too large, 2—too small, 3—correct.

Equipping cars with apparatus of too great capacity was no uncommon occurrence ten or fifteen years ago. This was largely due to careless or haphazard application, and partly because at that time the apparatus required was not yet developed to the extent which now prevails. The reason more complaint against over-powering is not heard is that it tends to secure two of the prime requisites of the ideal equipment—namely, maximum safety and maximum reliability, and also secures economy in equipment maintenance cost. However, such an equipment fails to secure maximum economy on account of its unnecessary weight, excessive consumption of energy, relatively high first cost and, therefore, high fixed charges. Indications that a car is too highly powered may be found in maintenance of schedules with an unusually large amount of series running, cars continually running ahead of schedule, very low temperature rise in

the apparatus, extraordinarily low maintenance cost. The most reliable of these indications is, of course, the temperature rise.

Equipping cars with apparatus of too little capacity is a much more serious matter, as this procedure secures none of the three prime requisites of an ideal equipment, neither maximum safety, maximum reliability, nor maximum economy. Many such cases have occurred through careless selection, but probably most of them have been due to limited finances and erroneous ideas of economy. Indications that a car is under-powered may be found in its inability to maintain schedules, high temperature rise in apparatus, excessive maintenance cost, failure of apparatus in service.

The maximum economy involves a balance among the items of first cost, fixed charges, car and equipment maintenance cost, energy consumption, and those other operating expenses which may be affected by the car equipment, such that the total annual expenditure chargeable to the equipment shall be a minimum. Relatively high first cost taken alone is, therefore, liable to be misleading, since the initial expenditure of a few extra dollars may secure features which will decrease depreciation, maintenance or energy consumption to such an extent as to pay the interest on the additional investment and also return a large portion of the capital each year. The purchase of manufacturer's standard apparatus also generally tends to economy, because the cost of special features is frequently out of proportion to their value.

Incorrect car speed may at times be remedied by a change of gear ratio or modification of motor airgap, as when a car is overpowered but the speed is too low, or when a car is underpowered and the speed is too high. If, however, the car is overpowered and the speed is too high, a reduction in speed decreases the duty on the equipment and it is still too large even to a greater extent than at first. Yet such a change will decrease the consumption of energy. If the car is already underpowered and the speed is too low, an increase in speed imposes greater duty on the equipment and its insufficiency for the service becomes greater than it was initially. Therefore, changing the speed of a car improperly equipped may be of little value or even worse than valueless.

The most valuable check on the application of an equipment to a certain service, when the car speed is correct, is found in the temperature rise of the motors. This may be obtained on a sample equipment or on the first equipments put in service before failure of apparatus or excessive maintenance cost becomes evident. Then in case an equipment is too small, steps may be taken to secure more powerful equipments, or at times conditions may be adjusted to prevent overloading such equipments before they have been damaged by continual abuse. In the interest of ideal operation, systematic checking of motor temperatures in service is recommended.

It is therefore evident that even with perfect apparatus, correct application of that apparatus is a vital factor in securing an ideal equipment. In order to make a correct application, detailed knowledge of the service conditions is essential. In addition to being composed of ideal parts, the complete ideal equipment meets the following requirements:—

Motor type suitable for service, trucks, wheel size and shop facilities.
Control type suitable for service and for desired type of car.
Collector type suitable for operation with the particular type of contact line involved.
Ample clearance around individual pieces of apparatus on the car and between the apparatus and top of rails.
Minimum number of motors consistent with the service requirements.
Minimum car speed consistent with a reasonable margin for meeting rush hour and holiday conditions.
Minimum capacity to perform the service with safe temperature.
Light weight.
High service efficiency.

The necessity for meeting the first four of these requirements in order to make an ideal application is self-evident, but possibly the other items require further comment. Regarding the number of motors on a car, within the limits of their proper application, double equipments are preferable to quadruple equipments because of their less weight, higher efficiency, lower maintenance cost, lower first cost and lower fixed charges.

The necessity for minimum practicable car speed arises from the fact that too high car speed produces unnecessary consumption of energy, imposes unnecessary duty on the electrical equipment, increases wear and tear on the entire car, particularly on the brake equipment, gears and wheels, increases wear and tear on the road-bed, distribution system and power apparatus, and increases the possibility of accidents.

The desirability of minimum practicable capacity of equipment is apparent, since greater capacity does not materially increase either the safety or the reliability of the equipment, but does decrease the overall economy as previously outlined herein.

In connection with weight, the ideal equipment is specified advisedly as having light weight rather than minimum weight, because the lightest equipment is not always the most economical. In the early stages of the movement to reduce the weight of cars and their equipments, there was a tendency for this one idea to overshadow all the other elements entering into real economy. The chief factor overlooked in this connection was the essential character of motor speed. The result was that light weight motors were built with such high speed that even with maximum gear reductions the car speeds were inordinately high. Such motors defeated the purpose for which they were designed in that the excess cost of energy for their op-

eration more than offset all economy in other items possible on account of the weight reduction.

High service efficiency is an essential of the ideal equipment because of its importance in securing maximum economy. Comparison of motor efficiencies alone is of little value in determining the efficiency of the complete car equipment, because the consumption of energy is greatly affected by the amount of rheostatic loss which, in turn, depends principally upon motor speed and the degree of saturation of the motor. Hence, in selecting the best from several available equipments, it is necessary to know their relative energy consumptions in the service to which they are to be applied.

When service conditions are unknown, or imperfectly known, crude methods are available for selecting an equipment but no assurance can be had that the application is ideal. For example—where a new line is being constructed, the service to be given is frequently uncertain and must be estimated on the basis of knowledge of and experience with existing lines in territory of similar physical characteristics and similar quantity, quality and distribution of population; the theory of probabilities being applied to approximate the all important items of schedules and frequency and duration of stops, due consideration being given to the service on competing lines if such exist. This being done an equipment may be chosen, maximum consideration being given to the proposed car weight.

If the problem is to replace old equipments with new ones for the maintenance of existing service, the conditions of which are unknown, and yet it is known that the old equipments are sufficiently large, it is easy enough to choose a new equipment of equal capacity and similar speed and tractive effort characteristics. However, the fact that an existing equipment is large enough is no proof that a smaller modern equipment would not have sufficient capacity for the service and be more nearly ideal in all respects. If the conditions are as described above, except that new cars of different weight are to be purchased, an equipment may be selected on the basis of the same horse-power per ton of car, always remembering that the characteristic curves between speed and tractive effort per ton must be similar for the two motors.

Some progress toward more nearly approaching the ideal application may be made in the last two examples, if the temperature rises attained on the old equipments are known. However, where such approximate methods of selection are used, it is only by accident that the application is the best possible, particularly when new equipments may include comparatively recent developments (such as field control and ventilation), which increase the service capacity of the motors without increasing their nominal ratings. Therefore, it is worth while to repeat that correct application requires detailed knowledge of the service conditions.

Lack of appreciation of the vital importance of this basic knowledge in making applications is accountable for the remarkable fact that many railway companies have only a general idea of what their service conditions really are and do not know accurately all of the service details which affect the duty required of their equipments. Misapplication of equipments has been responsible for enormous monetary waste through unsafe, unreliable and uneconomical service. Not only the railway companies have suffered but also the equipment manufacturers at times have been condemned for the inadequacy of perfectly good equipments for whose misapplication they were in no way responsible.

Many large railway companies by the purchase of trial equipment, and the manufacturers through their ability to conduct or assist in making service observations and tests, and to furnish engineering advice, are doing much to insure for each railway company the securing of ideal applications, as well as apparatus which is ideal in design and construction. The quantity of such service given by the manufacturers is the natural result of the rapid development of the electric railway industry and the resultant almost continuous change in types and details of apparatus. The amount has been further increased because engineers of railway companies have not always familiarized themselves with application work. Some railway companies have considered themselves financially unable to incur the expense connected with a detailed study of their service, other railway companies have been disinclined to make an expenditure for engineering service, and the manufacturers have been forced by costly experience to protect themselves against the results of misapplication.

"Know thyself" is an ancient injunction as valuable for use in the present and future as in the past. It may be applied to railway companies as to individuals and is essential for both in striving for the highest success. Progress toward complete self-knowledge and its rewards may be made by the railway companies by studying their service conditions more in detail. Systematic coöperative effort along this line and extended to cover the service conditions of all other apparatus as well as car equipments, will produce invaluable results for railway men in that, when considered in conjunction with operating costs, it will furnish each one a logical basis for determining whether he is providing maximum service in the transportation business at minimum unit cost for his conditions. Therefore, careful consideration of all phases of the problem of securing ideal application is suggested to the railway associations as an activity which will be of material assistance to their members and may modify the present state of affairs to the end that greater economy may be secured in the operation of railways.

A Universal Pressed Steel Railway Motor

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Engineering Department,
Westinghouse Electric & Mfg. Company

THE STANDARD street car motor today is a highly perfected piece of apparatus, having gone through long periods of development until the weak points of the early designs have been overcome. The demands of operators as well as the efforts of the manufacturers during the last few years indicate clearly, however, that further development is required. The principal demands now are:—

C. W. STARKER

1—Decreased bulk of the motor for a given output to permit larger capacities in a given space and a decrease in the height of the car floor, as well as the size and weight of the wheels.

2—Decreased weight of the motors, to reduce the expense for carrying around dead weight and to lessen track maintenance.

3—Definite performance, particularly motor speed, in order to secure a uniform distribution of current and heating between motors of the same car or train.

4—Definite guaranteed weight.

5—Accurate overall dimensions.

Items *3*, *4* and *5* will permit the preparation of definite specifications which hold the manufacturer to

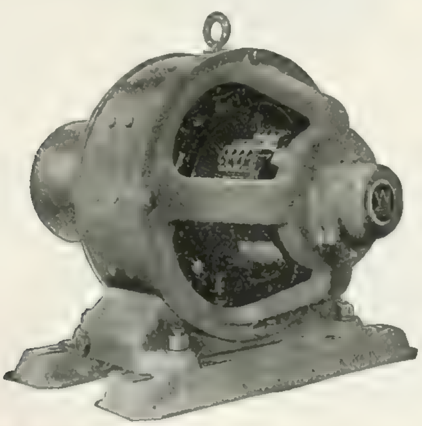

FIG. 1—100 HORSE-POWER DIRECT-CURRENT INDUSTRIAL MOTOR
Rolled steel frame; pressed steel feet; pressed steel slide rails. Designed in 1909.

certain high standards and insure at all times a sufficient amount of clearance.

There is also the demand for quick delivery. The best means of insuring quick delivery on apparatus involving highly specialized and extremely expensive tools is thorough standardization. That is, instead of the great variety of motors in use by different railway companies, a universally applicable motor must be adopted or at least a motor which adapts itself readily to essential modifications. Such standardization will then lead to large output so far as the principal parts of the motor are concerned, and will enable the manufacturer to devise special equipment to take care of production in the most effective manner. These considerations, which are by no means novel, led a little over a year ago to the design of the "universal pressed steel street car motor,"

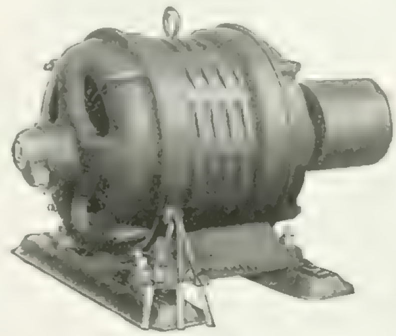

FIG. 2—TEN HORSE-POWER PRESSED-STEEL INDUCTION MOTOR
The "all steel" motor, having pressed steel frame, feet, slide rails and bearing brackets.

which is being shown for the first time, at the American Electric Railway Association Convention in Atlantic City.

Just as the fundamental considerations, as pointed out, are nothing but an application of old principles

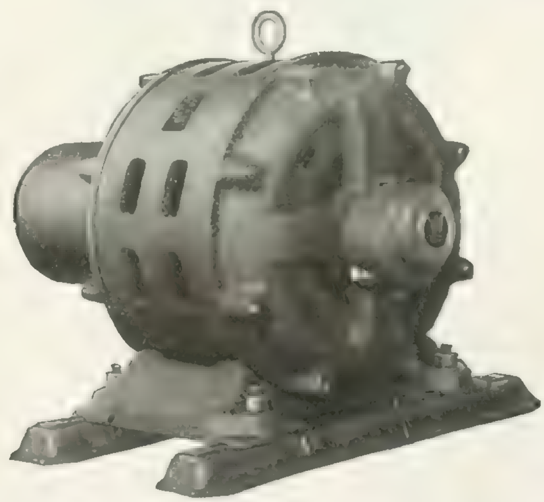

FIG. 3—50 HORSE-POWER INDUCTION MOTOR
Having rolled steel frame, feet and slide rails. Designed in 1911.

to a new field, so is the design and the manufacturing process of this pressed steel motor nothing but an application of well tried out designs and processes to a new class of electric motor.

In 1909 the Westinghouse Company first de-

veloped a standard line of pressed steel direct-current motors ranging from 2 to 150 horse-power and designed for general power purposes. This motor, illustrated in Fig. 1, had a frame ring made from open hearth steel plate, which has magnetic qualities about twice those of cast iron and better than those of cast steel, so that the adoption of this material at once made it possible to cut the weight and bulk of the old cast-iron magnetic section in half and to avoid the uneven magnetic properties, the blow holes and the machining difficulties inherent to steel castings. The feet and slide rails of the motor were made from heavy open hearth steel plate formed under hydraulic presses. The motor feet were united with the frame by numerous rivets, large in cross-section, driven hot on a 100 ton hydraulic riveting press. Many thousands of these motors have been placed in service during the last four years

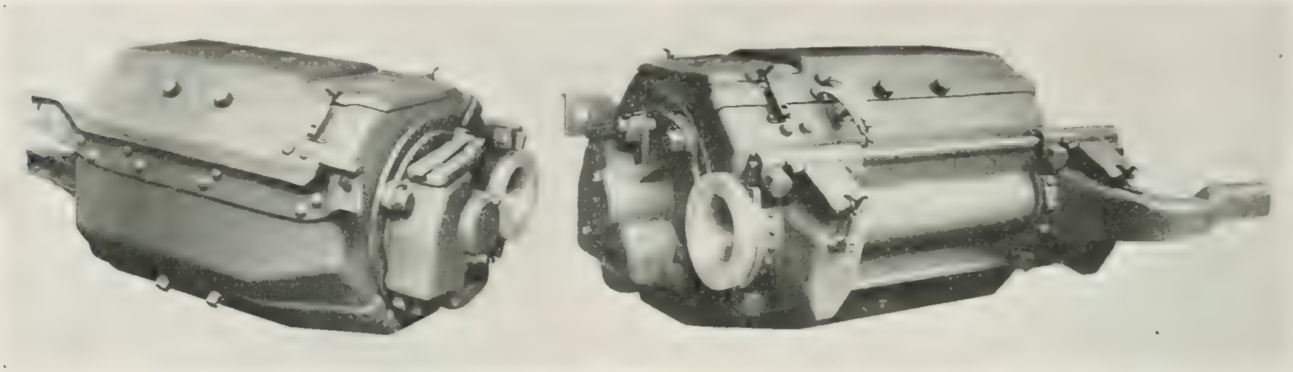

FIG. 4—FRONT AND REAR VIEWS OF WESTINGHOUSE PRESSED STEEL RAILWAY MOTOR
Standardized outline dimensions; uniform speeds; even distribution of load and heating; reduced and uniform weight.

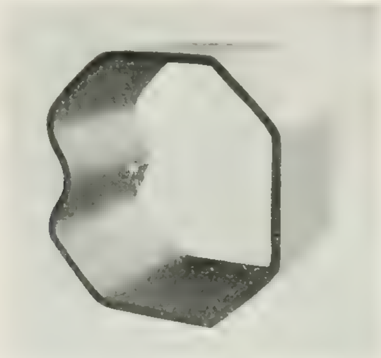

FIG. 5—PRESSED STEEL YOKE
Forming the main magnetic section of the motor. Made from high permeability open-hearth steel.

and have given such universal satisfaction under most severe operating conditions, that a few years later a standard line of alternating-current motors was brought out, embodying the same features. This line of alternating-current motors ranging from 2 to 200 horse-power for all different speeds, voltages, frequencies and phases, has been designed and in successful use for several years for all classes of service, including mill and hoisting work, which in the severity of its demands closely approaches that of street car work. These years of actual service of these motors have definitely established the absolute reliability of the riveted joint between motor frame and base. Before these motors were placed on the market, extensive studies and experiments were made to establish proper methods and to obtain proper materials to insure reliable, tight fitting rivets in all cases. Rivets are trusted implicitly in locomotive construction, in bridge and structural work, car trucks, boilers, automobiles and, in fact, wherever steel plate is used. The same trustworthiness of properly made rivets has been proven in their application to electric motors. This all steel alternating-current motor, modified in details for small and for larger capacities, but in the general principle of its mechanical construction iden-

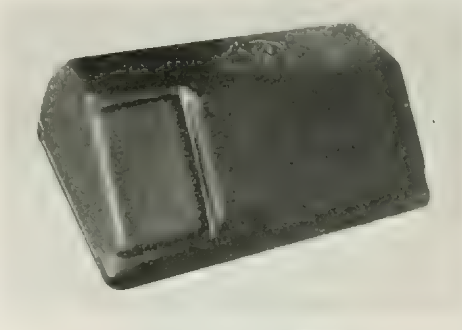

FIG. 6—FRAME HALF—SUSPENSION SIDE

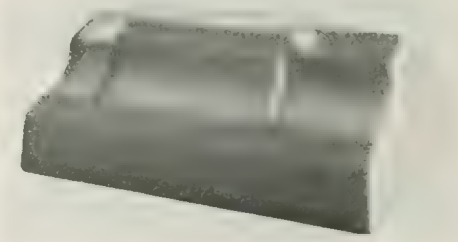

FIG. 7—FRAME HALF—AXLE SIDE
Rough forgings as they come from the press. The lower half is formed to receive the axle bracket. The commutator opening of the upper half, and the semi-circular openings in the ends of each half for the bearing housings are punched out in the next operation.

tical with the direct-current motor described above, is shown in Figs. 2 and 3.

After the details of construction and manufacture which make for success had been studied and

worked out in these types of motor for over five years, it was the next and logical step to develop a pressed steel railway motor. This new motor in its finished form is shown in Fig. 4.

The yoke, Fig. 5, is made from a thick slab of open hearth steel, as in the other types, except that

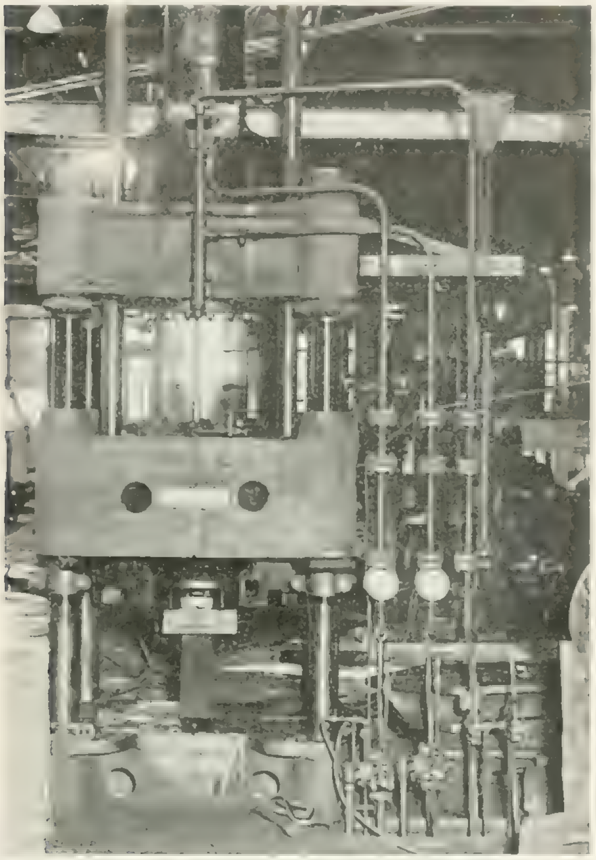

FIG. 8—A 540 TON DOUBLE ACTING HYDRAULIC PRESS OF SPECIAL DESIGN

Used for the manufacture of the frame halves (Figs 6 and 7).

instead of being circular, it is of octagonal shape, conforming to railway motor practice. This yoke from high permeability steel forms the main magnetic section of the motor. It is pressed very accurately to

FIG. 9—AXLE BRACKET

Forged hot from heavy steel plate on the 1 000 ton press (Fig. 10.)

shape in large dies and goes through a number of operations before the finished shape is reached.

The frame halves, illustrated in Figs. 6 and 7, are formed in dies from open hearth steel plate of comparatively light section. This difficult forming work, involving a series of operations, is accomplished by a special 540 ton double-acting hydraulic forging press, installed for the manufacture of pressed steel motors and illustrated in Fig. 8.

The axle bracket, Fig. 9 is, in much the same manner, formed from heavy steel plate of a special grade on a 1 000 ton steam-hydraulic forging press.

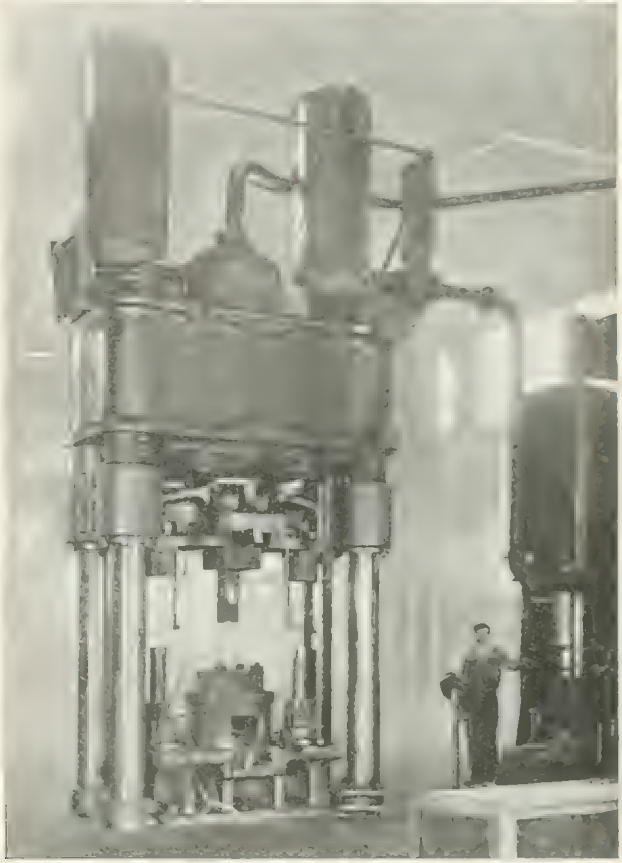

FIG. 10—A 1 000 TON STEAM HYDRAULIC FORGING PRESS

For pressing large parts from heavy steel, such as the axle bracket (Fig. 9) of the pressed steel railway motor.

This press, one of the most modern and most effective tools, is illustrated in Fig. 10. Incidentally, it may be mentioned that the material for these forgings, as well as for the yoke forging, is of a special grade of steel bought under strict specifications. The materials are rigidly inspected and test specimens of each heat are tested in the physical and chemical

For supporting the motor on the truck. It is hot-forged from a steel bar.

laboratory before they are used in the forging department.

The parts described are then assembled into the frame unit, Fig. 12. The frame halves fit tightly over the yokes and their ends overlap to make a tight joint. The axle bracket is so formed as to fit into the recess of the frames, and pockets, reinforced by U-sections, are provided to receive the 12 large rivets which, ex-

tending through the heavy yoke, unite the frame and axle bracket. At each end the frame halves are joined together and reinforced by two heavy forged steel rings. In addition to this, there is provided a

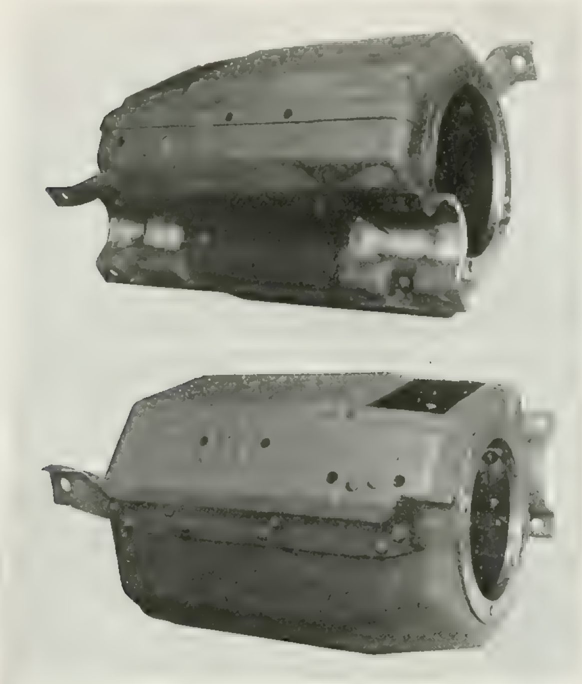

FIG. 12—COMPLETE FRAME

All rivets are of large cross-section, driven hot under 50 tons pressure and extending through the heavy yoke (Fig. 5), frame halves (Figs. 6 and 7), and the axle bracket or suspension bar (Figs. 9 and 11). The weight is 30 percent less than that of a cast-steel frame.

reinforcing forged steel shoe which transmits directly the strain between truck axle and motor shaft.

The suspension bar, Fig. 11, is formed from angle iron on the bulldozer shown in Fig. 13 and is riveted to the motor frame and through the yoke by a number of large rivets. All this riveting is done on the 50 ton hydraulic riveter shown in Fig. 14.

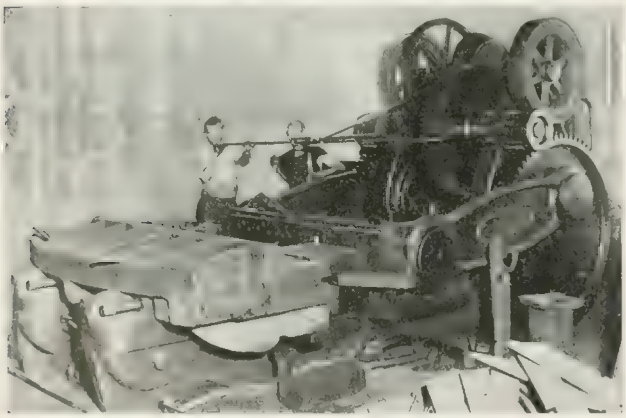

FIG. 13—A POWERFUL ELECTRICALLY-DRIVEN BULLDOZER

Used in the manufacture of the yoke (Fig. 5) and the suspension bar (Fig. 11).

The axle cap, shown in Fig. 18, is also made from forged or pressed steel. Although greatly increasing the cost of tools and equipment, this construction allows a reduction in weight and an increase in strength and rigidity which would be impossible with cast steel. The axle cap proper, Fig. 15, takes up the strain from the axle. This piece is of liberal thickness. The flanges at the ends very much increase the rigidity and take up the end thrust on the flanges of the axle bearings.

Over this axle cap fits the oil box, Fig. 16, made from comparatively light cold-rolled sheet steel. Its function is to hold oil and waste; not to take strains aside from those occuring in handling. Instead of 1/4 or 3/8 inches, the minimum thickness for steel castings, this box may therefore be made from 1/8 or 5/32 inch cold rolled sheet steel and therefore, the dead and useless weight of this part is reduced in just that proportion.

Both axle caps are alike, except that the one on the pinion end has a forged steel gear case arm, Fig.

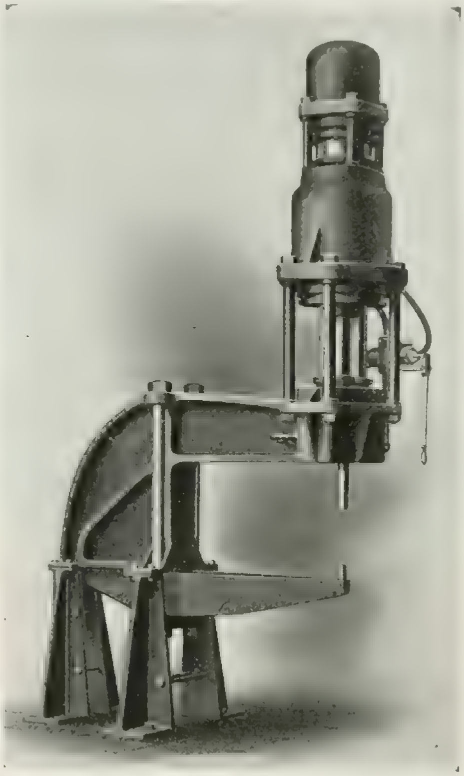

FIG. 14—50 TON HYDRAULIC RIVETING PRESS

Specially designed for riveting pressed steel railway motors.

17, in addition. This arm is made comparatively heavy and of a particularly deep U-section, as under certain conditions it may have to transmit severe stresses. As it spreads out towards the end, the U-section gets deeper. It has a very rigid curved flange and is riveted with an ample number of large hot-driven rivets to the heavy piece forming the axle cap proper. All of these are factors which increase rigidity and strength, and make this gear case arm a most reliable part of the motor. However, if an accident happens, as for instance, the car running up on a manhole cover or a large stone, this forged steel arm may bend perhaps, but will not break like a casting. It can be straightened out or taken off and replaced without the

expense and inconvenience caused by a break of an entire axle cap as has sometimes occurred in the case of a casting.

The neat and light pressed steel commutator cover, Fig. 19, and the pressed steel, felt-lined oil lids, both with deep and non-varying grooves all around for shedding water, are also worth mentioning. The seats for both covers are wide,—wider and truer than customary on cast frames—giving an additional guarantee for tightness. Cover catches of a design the same as the catches in general use on automobile hoods are used on commutator cover and oil lids, the same detail being used on all covers. This catch is operated by an enclosed spiral spring which, as it should, exerts full tension in the closed position of the cover.

FIG. 15—AXLE CAP WITH FLANGES

Pressed from especially thick steel plate.

FIG. 16—OIL BOX

There is no welding on this piece; it is pressed from a single piece of cold rolled sheet steel.

Excessive weight is particularly undesirable in accessories to the motor which fulfill requirements of only secondary importance, such as for example the axle collars. The function of these axle collars is to take up the space between the flange of the axle bearing of the motor and the hub of the car wheel. This space ordinarily varies from about 3 up to 12 inches and if designed from cast iron these axle collars add very materially to the weight of the equipment. Pressed steel instead of cast iron is now being introduced on all these parts. Fig. 20 shows two axle collars, one of the old cast iron construction, the other one of pressed steel. The latter construction not only cuts the weight in two, but also is stronger, unbreakable and, therefore, more reliable than cast iron. The adjusting feature, an adaptation of the saw-tooth principle, allows wear of the flange of the axle bearing to be taken up with a minimum amount of trouble, over a wide range and in very small steps. These axle collars are supplied with or without the fiber disc shown riveted to the flange in the illustration. The function of this fiber disc, when used, is to lengthen the time between adjustments by reducing the friction between the collar and the axle bearing.

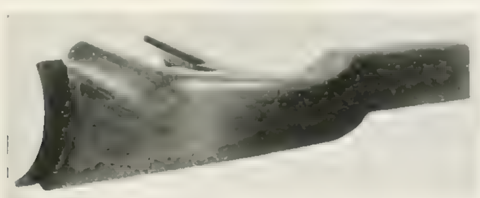

FIG. 17—GEAR CASE ARM

Pressed from heavy steel, with flanges and a deep U-shaped section.

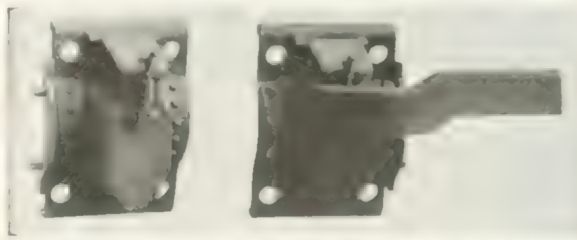

FIG. 18—AXLE CAPS COMPLETE [illegible]

All parts are made from pressed steel, hot riveted together on the 50 ton press. They are unbreakable, are stronger than cast steel and about 40 percent lighter.

In general appearance the new motor is not essentially different from the present types; in fact it is directly interchangeable in rating and overall dimensions with one of the most popular of present railway motors.

FIG. 19—PRESSED STEEL COMMUTATOR COVER

The catch shown at the right engages the holes punched in the cover and pulls the cover tight by means of a spiral spring inside the barrel of the catch.

The development of pressed steel railway motors is, on account of the cost of equipment, limited for some time to come to the most popular ratings, about 30 to 50 horse-power. Similar development on larger sizes is quite possible, and would give even better results, especially with regard to weight reduction. These benefits, however, cannot be obtained until there is a sufficiently large demand for these sizes, as well as a greater inclination to adhere to standards.

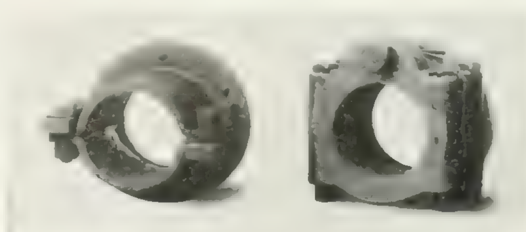

FIG. 20—AXLE COLLARS

The pressed steel collar, at the left, is unbreakable, is stronger and about 50 percent lighter than the cast iron collar at the right. It is easily and positively adjusted by a drop-forged, saw-toothed distance piece.

With reference to the universal features, it is apparent that the magnetic section or yoke, Fig. 5,

may be varied in width and if necessary in thickness for different motor capacities, without in any way effecting the external dimensions of the motor. Also, while the outside dimensions are suitable for any normal truck and do not exceed those of the present motors, there is more room on the inside, due partly to the higher grade of material used and partly to the greater accuracy of the pressed parts as compared with rough steel castings. This allows a comparatively wide margin for variations of field windings or insulation. Further in an axial direction, it allows variation in width of the armature core and field poles, in coil space or space for blowers. As for mechanical variations in the main pressed parts, it is evident that absolute adherence to the standard is essential. Variations in gear ratio, center distance between gears, road clearance and method of suspension can within certain limits be taken care of with comparative case for the reason that the suspension bar, axle bracket and gear-case arm are non-integral parts of the motor frame.

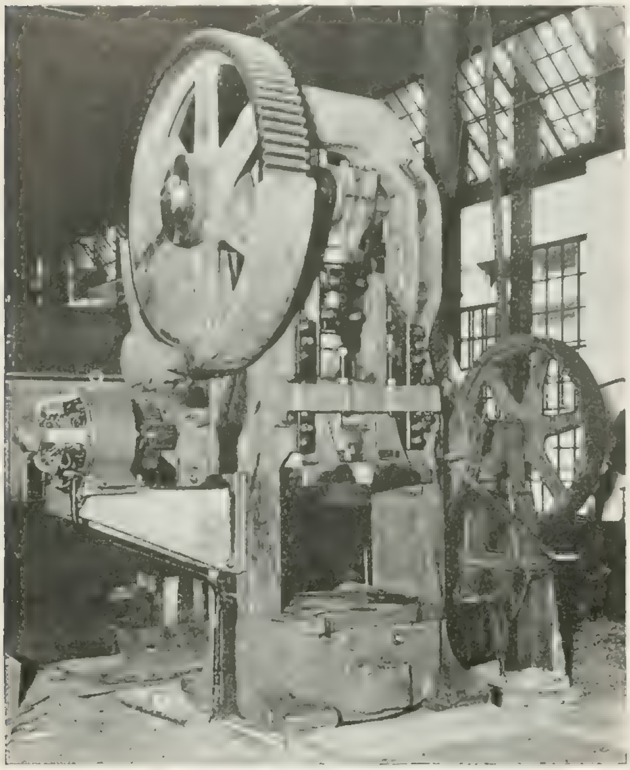

FIG. 21—A LARGE MOTOR-OPERATED ECCENTRIC PRESS
For punching and forming pressed steel parts.

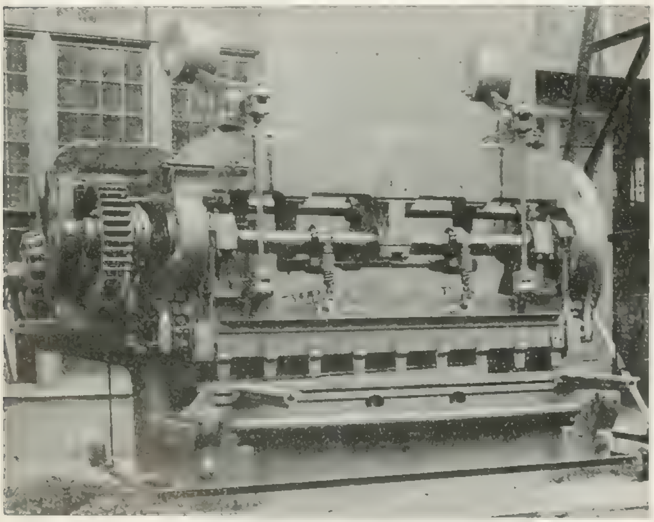

FIG. 22—ELECTRICALLY OPERATED SHEARS USED IN TRIMMING STEEL PLATES

Figs. 21, 22 and 23 show additional presses and shears, installed for the manufacture of pressed steel motors. The size and variety of these tools give an idea of the enormous investment in dies and equipment necessary to produce pressed steel railway motors. Such equipment is justified only by production on a large scale, and the full benefit for both user and manufacturer will be derived only by adopting a standard and universally applicable motor such as described.

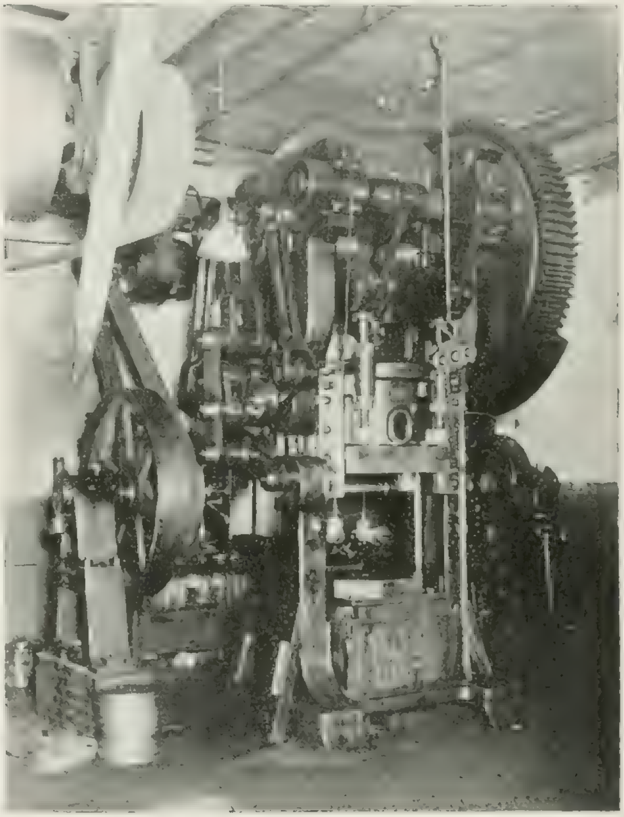

FIG. 23—A MOTOR-OPERATED DOUBLE-ACTING TOGGLE PRESS
For cold drawing pressed steel motor parts.

While the Westinghouse pressed steel universal railway motor marks a step of progress, and in a way is a new departure, all the elements of construction which have entered into design or manufacture had been tried out and proven before, and particular care has been taken to retain and incorporate in the new design all those points which have established the reputation of modern railway motors for reliability in service.

The Visalia Electric Railroad

W. P. L'Hommedieu
San Francisco Office,
Westinghouse Electric & Mfg. Company

In Tulare county, California, in the heart of a rich citrus fruit district, is located the first 15 cycle, single-phase interurban electric railway to be placed in operation in this country. As it stands completed today this road extends from Visalia to Exeter, a distance of 10.1 miles, and thence to Lemon Cove, 10.8 miles further. From Lemon Cove the line has been extended on to Red Banks, a distance of eight miles. A branch line from the Red Banks extension starts at Woodlake, six miles from Lemon Cove, and runs out into a newly developed orchard tract, a distance of 2.3 miles, with two miles additional now under construction. At Lemon Cove another branch line runs out to what is known as Terminus on the Kaweah River. The bathing and picnicing facilities at this place have made it desirable for the railroad company to make special provision for Sunday and holiday pleasure seekers. The conveniences so provided, together with the special Sunday and holiday excursion rates which have been placed in effect have made this resort a source of increased passenger revenue.

All of the system, with the exception of the yards in Visalia, Exeter and Lemon Cove, is single track, and is owned by the railway company, except for the section between Visalia and Exeter, which is jointly operated by the Visalia Electric Railway Company and the Southern Pacific Railroad, it being a part of the Southern Pacific main line between Goshen Junction and Hanford. The total single track mileage, including the portion which is jointly operated and including turnouts and yard sidings, is 45 miles.

The first ground was broken for the Exeter-Lemon Cove section of the road on March 15, 1905, and in November of the same year the grade between Exeter and Lemon Cove was completed and ready for the track. Track laying began in June, 1905, on the Lemon Cove end of the line and the work was completed the following December. Steam locomotives were put in service immediately after completion of the track, steam service being continued until superseded by the electrical equipment.

Meanwhile a careful investigation of various proposed electrification schemes was being carried on to determine what electric system should be installed. While the plan was to develop only a comparatively short road at the outset, the ultimate idea was that it would probably be expanded to become an important link in a large electric railroad system, which should cover that section of the San Joaquin Valley. With this idea in mind all systems having restricted fields of operation were eliminated from consideration and single-phase trolley current, at 3 300 volts, 15 cycles, with Westinghouse equipment was selected. Steam service was discontinued and electric operation commenced in March, 1908. About one year later the line to Redbanks was constructed and service extended over it.

The portion of the line from Exeter to Lemon Cove is constructed with fifty pound rails; but on the newer extension to Redbanks, seventy-five pound rails were employed, owing to the decision at that time to put heavier passenger cars in service and the greater weight of freight trains that it then became evident would have to be handled. The track from Visalia to Exeter is laid with ninety pound rails. The entire roadbed is sand ballasted and little or no difficulty has been experienced in spite of the large cars and heavy freight haulage which takes place during certain seasons of the year. Rails are bonded at every joint and cross bonds are installed at frequent intervals. The track is standard four feet, eight and one-half inch gauge. The maximum grade is one percent in the vicinity of Lemon Cove Station.

OVERHEAD CONSTRUCTION

The overhead construction is of the bracket type throughout with the exception of the various packing house yards and the car barn approaches, where span construction is necessitated. Wood poles with wood bracket arms are used. The pole spacing is 120 feet on the tangent with single catenary suspension having twelve hangers per span. The two mile extension now under construction will have 150 foot pole spacing with 10-point suspension, using a more modern type of catenary hanger. A 3/0 trolley is supported from seven-sixteenths inch steel messenger cable. Both rigid and flexible hangers are in use, the later type being flexible, as experience has demonstrated that the trolley wear is lessened by using a hanger having considerable upward play in the messenger cable. The trolley wire is maintained at a height of 22 feet above the rail. All motor cars and the locomotives are equipped with the sliding shoe type of pantograph trolley, which is the recognized standard for alternating-current high-voltage trolley operation. The upward pressure of the pantograph is maintained at approximately ten pounds.

POWER SUPPLY AND STATION EQUIPMENT

Power for operating this system is purchased from the Mt. Whitney Power & Electric Company. This is furnished the railway company at 35 000 volts, three-phase, 60 cycles and is metered on the high tension side of the step-down transformers. It is stepped down to 2 200 volts, three-phase, 60 cycles, by single-

phase transformers and then changed to 11 000 volts, fifteen cycles, single-phase, by synchronous motor frequency changer sets, in the main frequency-changing substation at Exeter.

There are three transformer substations:—One located about eight miles from Exeter toward Lemon Cove; one about eight miles from Exeter towards Visalia; and the third located at Woodlake, seventeen miles from Exeter.

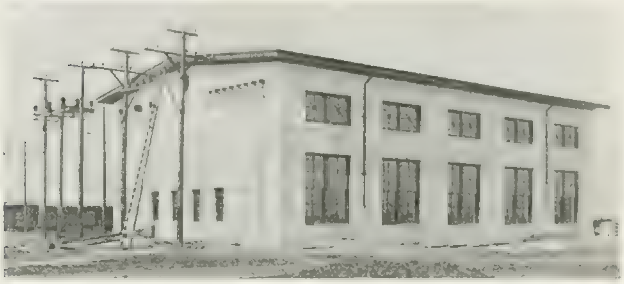

FIG. 1—SUB-STATION OF THE VISALIA ELECTRIC RAILROAD AT EXETER, CAL.

The main substation at Exeter is a substantial concrete structure of pleasing appearance, built in the old Mission style, with steel roof trusses, and contains a traveling crane of ample capacity. The ground space occupied by this building is approximately 56 by 83 feet. The building is divided longitudinally by a concrete fire-proof wall, the frequency changer sets, switchboard and exciter being installed in the main section of the building and the transformers in a separate room. The lightning protective and high-tension switching apparatus is installed in galleries at one end of the building beneath which are the general offices of the company. The car barns and machine shop are in a separate building, occupying a ground space of about 100 by 200 feet. A number of suitable pits are provided for the proper inspection of the rolling stock.

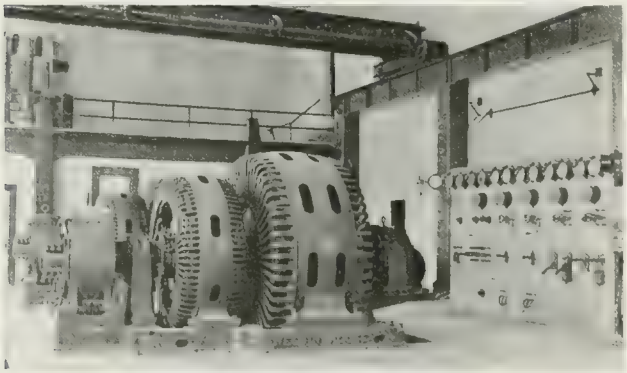

FIG. 2—INTERIOR OF EXETER SUB-STATION

The main frequency changer substation is designed to contain three main units, two only of which have been installed. The equipment in this station comprises two two-bearing motor-generator frequency changer sets, each composed of one 540 horsepower, synchronous motor wound for three-phase, sixty-cycles, 2 200 volts, with an induction starting motor on an extended shaft, direct-connected to and mounted on the same shaft and bedplate with one 375 kilowatt single-phase generator, wound for fifteen cycles, 11 000 volts. The single-phase generator is designed so that, by means of a Tirrill regulator, normal voltage can be maintained with full-load output at forty percent power-factor. Mounted on the extended shaft of each frequency changer set is a 125 volt exciter of proper capacity to excite both of the alternating-current generators when they are delivering 25 percent above normal rated output at 40 percent power-factor.

For exciting the synchronous motors of these sets there is installed one 125 volt exciter, direct connected to and mounted on the same bedplate with a three-phase, 60 cycle, 200 volt induction motor. This set has sufficient capacity to excite the two synchronous motors now installed.

For stepping down from 35 000 volts to the synchronous motor voltage there are installed six 150 kilowatt, oil-insulated, water-cooled transformers, wound for single-phase, 60 cycles, 35 000 to 2 200 volts, and connected in two banks of three transformers each, delta-delta. Smaller auxiliary transformers are installed to furnish current for the motor-driven exciter and the starting motors of the sets as well as for the station lighting and for a motor-driven pump for the transformer cooling water.

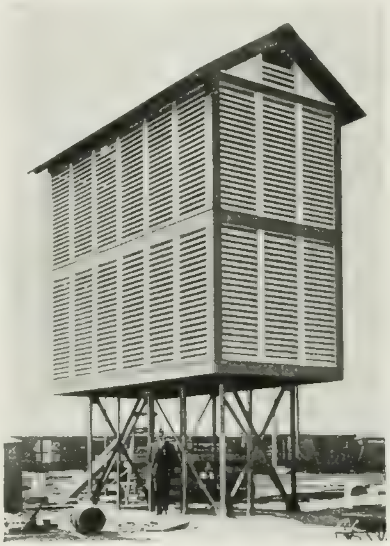

FIG. 3—WATER-COOLING TOWER AT EXETER SUB-STATION
Supplying cooling water for the transformers.

The equipment is controlled through a six panel switchboard including two synchronous motor panels, two single-phase generator panels, one double exciter panel for the direct-connected exciters, and a panel for the motor-generator exciter. Remote mechanically operated oil switches are used for the 35 000 volt incoming three-phase line and the 11 000 volt single-phase outgoing feeders. Low equivalent multigap lightning arresters with oil insulated choke coils are installed for protection on both the incoming and the

outgoing lines. Two 300 kilowatt, single-phase, 15 cycle, oil-insulated, self-cooling transformers are also installed in this station for converting from 11 000 to 3 300 volts, feeding directly to the trolley at this point. The transformer cooling water is circulated through a cooling tower located just outside the substation building.

The 11 000 volt, 15 cycle, high-tension feeder transmission lines from the main substation at Exeter to the three transformer substations consist of two No. 3 B. & S. gage bare copper wire carried on the main trolley poles.

Each of the three transformer substations contains one 300 kilowatt, single-phase, 15 cycle, oil-insulated, self-cooling transformer, for converting from 11 000 to 3 300 volts, together with high and low-tension oil switches and lightning protective apparatus. These substations have space provided for a duplicate set of transforming and protective apparatus. The small size of these stations, coupled with the fact that there is no rotating apparatus installed, makes an attendant unnecessary. A regular monthly inspection by the chief operator at the main frequency changer substation is all the attention required for these transformer substations.

FIG. 4—VIEW SHOWING OVERHEAD CONSTRUCTION

ROLLING STOCK

Passenger Cars—The present rolling stock of the company includes four 42-ton passenger coaches, two of which have baggage compartments, the remaining two having accommodations for passengers only, each of which is equipped with four Westinghouse, 75 horse-power, single-phase, 15 cycle railway motors with battery energized unit switch (AB) control, and automatic air brakes. The cars have 36 inch wheels and use a gear reduction of 60 to 17. There are also two trailer coaches of the same design as the four motor cars, and two 54-ton steel passenger coaches, each equipped with four Westinghouse 100 horse-power railway motors and battery energized unit-switch group control. These cars have 36.5 inch wheels and use a gear reduction of 63 to 20.

All motor cars are provided with nine-wire train lines for train operation, and the design of the equipment of the 54-ton cars is such that these can be operated in trains with the small cars, the equipments each handling their respective shares of the load. Automatic acceleration is provided for by the control equipments.

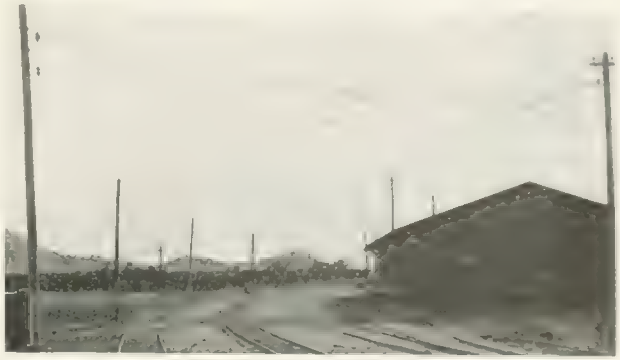

FIG. 5—CATENARY OVERHEAD CONSTRUCTION IN THE LEMON COVE YARD

The four motors on each car are connected in pairs, the two motors in each pair being permanently in series. The trolley voltage is stepped down to the proper voltage for the motors through a single-phase auto-transformer, which is also provided with the necessary taps for securing acceleration without the insertion of resistance, and for supplying power for car lighting and the compressor motor. Preventive coils are connected between the successive transformer taps, on the different control steps, during acceleration.

Freight Equipment—For hauling freight traffic, there is one 47-ton Baldwin-Westinghouse electric locomotive of the double swivel truck class with box type cab. This locomotive is equipped with four 100 horse-power motors and battery energized unit-switch (HB) control. Westinghouse air brake equipment is used, including two air compressors, providing straight air operation of the brakes on the engine and automatic operation for both the engine and train. In general, the overall dimensions of this locomotive are:—

FIG. 6—COMBINATION PASSENGER AND BAGGAGE CAR

Distance between coupler knuckles....	32 ft. 2 in.
Overall width	[illegible]
Total height over car roof	[illegible]
Total wheel base	21 ft. 1 in.

Forced ventilation is provided by means of a separate motor-driven blower, for both the motors and the transformer, which is of the air-blast type. The locomotive is capable of exerting a continuous tractive effort of 5 900 pounds at approximately 23 miles per hour. The full-load tractive effort at the one hour rating of the motors is 11 350 pounds at 17.3 miles per hour. With clean dry rails the maximum tractive effort which can be exerted by the locomotive is 23 500 pounds.

The heavy freight traffic on this road takes place during the months of October, November, December and the first part of January, which is the packing season for the citrus crop. During these months in the season of 1913-14 this one locomotive handled over 1 200 cars of oranges and lemons. Throughout the fruit packing season positive and unfailing service is demanded from this locomotive—any failure which would cause it to miss a single scheduled trip would entail the loss of probably the entire shipment of fruit which was then prepared for movement. The growth of the freight business handled over this system has been very rapid and last season's tonnage was between three and four times the tonnage handled five years ago.

SERVICE AND OPERATING RESULTS

The present passenger schedule of the road provides for a total of two round trips between Visalia and Lemon Cove and seven round trips between Visalia and Woodlake, two of these latter trains running on to Redbanks. The running time one way from Lemon Cove to Visalia is 56 minutes for practically all trains, there being about nine stops made, thus making a schedule speed of 22.5 miles per hour. It is possible with the equipments in service to reduce considerably the scheduled running time, but since the schedule is largely determined by connections with steam trains, there is no necessity for doing so. The average daily car mileage made by the passenger equipment is 545 miles.

Figures compiled for the operating records for the last quarter of 1913 show that the average maintenance cost of equipment was as follows:—

Cost of electrical and mechanical repairs and renewal of parts of passenger and combination cars, including motor and control equipment, air-brake equipment, trucks and bodies, 1.839 cents per car-mile.

Cost of electrical and mechanical repairs and renewal of parts of locomotive, including motor and control equipment, air-brake equipment, cab and trucks, 1.134 cents per locomotive-mile.

Total cost per car-mile of both passenger and locomotive equipment, including the cost of inspection, oiling, car cleaning, etc., 2.487 cents per car-mile.

No recent attempt has been made to compile accurate data on the power consumption of the equipment for this system. However, about three years ago exhaustive tests were made to procure such information, and at that time it was found that the average was 77 watt-hours per ton-mile at the switchboard, which included the power consumed by both passenger cars and locomotive. Over a three months' period, readings taken from meters connected on the 3 300 volt side of the car transformers showed that the average power consumption of the passenger cars was 58 watt-hours per ton-mile.

Considerations in the Design of Railway Motors

R. E. Hellmund
Railway Engineering Dept.,
Westinghouse Electric & Mfg. Company

In designing a railway motor the engineer is, as in case of any other engineering undertaking, continuously confronted by the fact that the best he is able to accomplish is only a good compromise. Between the multitude of facts to be considered and the requirements to be met there is confliction to such a degree that an improvement in one respect often necessitates the sacrifice of some other advantage. Therefore, the art of designing a railway motor consists of properly considering all the facts and requirements and studying their relative importance, followed by an attempt to fulfill as many of the requirements as possible, either partly or entirely, giving preference to those which have been found to be of greater importance than others. The more the designing engineer succeeds in this attempt the better will be his final compromise, which means the better will his motor be adapted to do the work for which it is intended.

With this admission that the finished product cannot be perfect in every respect, it is proposed to give here an enumeration of a number of the more important requirements in the design of railway motors and a discussion of the reasons why the same can or cannot be fully met in every respect. It is believed that such a discussion will not only familiarize the operating engineer with some of the problems met by the designing engineer, but it will possibly lead to a closer coöperation between the two, which in turn will inevitably lead to better balanced designs and constructions of railway motors.

The assistance which the operating engineer can give the designing engineer is manifold. The former is in a much better position than anyone else to study

the service requirements by the proper collection and compilation of operating data, especially such information as brush wear, commutator wear, wear of bearings, expenses for all kinds of repairs, etc. By placing such information in the hands of the designing engineer, the latter will be enabled to get a broader and more exact view of the relative importance of the various requirements the motor must meet. It is essential in this connection to have accurate records of the direct and indirect expenses caused by the maintenance of the motors, in order to avoid wrong conclusions. It often happens, for instance, that certain features, while appearing to be very troublesome in the mind of operating men, prove to be, upon closer investigation, of rather small importance with regard to expense; while on the other hand, it is often the case that a considerable amount of expense for maintenance is involved without this being brought to the attention of the manufacturer. Quite often an exact knowledge of such expenses on the part of the designing engineer will soon lead to a proper remedy, in some cases even without noticeably adding to the cost of manufacture. In other cases, the operating engineer can often assist himself by making suggestions for changes in design, and last, but not least, he can do much good by issuing the proper specifications for the purchase of motors.

WEIGHT AND DIMENSIONS

The design of a railway motor is in many respects handicapped to a very large degree by two very important conditions existing in railway work, namely, the necessity of minimum weight and the limited space available for the motor. The reasons for the desirability of light weight are evident, namely, that every pound which has to be carried about with the vehicle requires a certain amount of power consumption and also additional track maintenance. The space limitations are well known. It is evident that the motor cannot be any wider along the shaft than there is space between the wheels. While this limitation is usually no great handicap in the design of motors up to about 60 to 75 horse-power, it represents a very serious limitation in most motors of large ratings. Further, the vertical height of the motor is limited by the necessity of a certain clearance below and above the motor and the desirability of keeping the floor of the car as low as possible. While in the past this limitation was serious only with the larger ratings, it has recently become one of the most serious handicaps in design in connection with almost all sizes due to the fact that the size of the wheels and the height of the car floor are being reduced to the very minimum, while at the same time the requests for large clearances below the motor have been most exacting in some cases.

The above limitations are usually readily understood by everybody, but they are trifles as compared with the space limitations a designing engineer must meet on account of the necessity for keeping the gear center distance small, the importance of which is not always fully realized by the operating engineer. In about 80 percent of all motor applications, the use of a very large gear reduction is of utmost importance in order to keep the current consumption within economical limits. This is due to the fact that the current for a given tractive effort will be less, as the gear ratio of the motor is increased. Thus referring to Fig. 1, it will be seen that the maximum size of the gear D_1 is limited by the wheel size D and the minimum permissible clearance under the gear case, A. If it is further assumed that the minimum pinion diameter D_2 has been adopted, based upon consideration of pinion wear, size of motor shaft and the strength of the pinion between the key and the root of the teeth, only the distance B is available for the motor between the motor center and the axle bearing. This space is, in all but very few cases of large wheels and small motor ratings, very much less than is necessary for an ideal electrical and mechanical motor design. For this reason it is against the operating engineer's own interest to insist upon anything which will lead to still worse conditions. For instance, he should avoid the use of unnecessarily large axles and unnecessarily heavy axle bearings. He should further avoid calling for unnecessarily large clearances below the gear case because this again will reduce the space available for the motor, as well as reduce the maximum gear ratio to some extent on account of the reduction in the gear diameter, as shown in Fig. 2. In many cases requirements have been such, especially in the case of motors for low floor cars, that it was impossible to use the maximum gear ratio and the operating company was obliged to foot the bill in the form of higher current consumption and increased heating of the motor. It follows directly from Fig. 3, for instance, that if the clearance below the gear case of Fig. 1 were to be increased in a case where it is impossible to further reduce the dimension B of the motor, there is only one

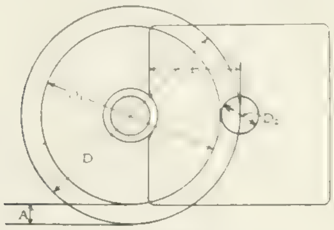

FIG. 1

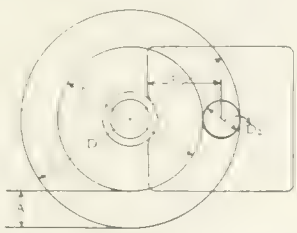

FIG. 2

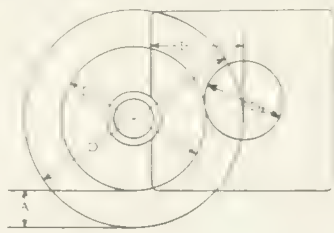

FIG. 3

FIGS. 1, 2 AND 3—DIAGRAMS SHOWING SPACE LIMITATIONS AND RELATIONS BETWEEN MOTOR SIZE, GEAR RATIO, WHEEL SIZE AND CLEARANCES

thing possible, namely, to increase the pinion as much in diameter as the gear has to be decreased, resulting in a material change in gear ratio. In one instance, an increased gear case clearance of only one-half inch changed the gear ratio from 15 : 57 to 18 : 54, which, in city service, may mean an increase in power consumption of 10 to 15 percent, causing at the same time a correspondingly increased heating of the motor. In many cases where an increased gear ratio is not advantageous with regard to power consumption or the like, it may still be a desirable feature by making the use of a motor with higher speed possible, which means a reduction in the weight and cost of the motor. These conditions cannot be too strongly impressed upon the engineer who writes the motor specifications, especially in the case of low floor cars and in the case of all motors rated above 75 horse-power. With motors below this rating on 33-inch wheels, this point is usually not of such great importance. It may also be of less importance in high speed interurban and trunk line service, where the maximum gear ratio cannot be used to good advantage.

COST OF MANUFACTURE AND MAINTENANCE

The cost of manufacture of a railway motor should be kept in mind by the operating engineer as much as by the designing engineer. It should be realized in this connection that the work for which a railway motor is intended, does not consist merely in propelling a car but also in giving the public the best possible traffic service at a minimum cost, yielding at the same time a fair profit to the operating company as well as to the manufacturer of the motor. The fulfillment of all of these conditions is materially assisted by low first cost. For this reason the operating engineer should be careful not to specify features which will give only a small advantage while materially increasing the cost of the motor. On the other hand, the first cost of the motor should be of secondary importance if features may be secured which mean a reduction of maintenance cost more than offsetting the additional first cost. It is very unfortunate in this connection that in many negotiations the first cost of the motor is the only consideration, no matter how much might be saved in maintenance cost by securing some very advantageous features. A change in attitude in this particular respect can only work out to the advantage of the purchaser.

STANDARDIZATION

One of the most fruitful fields of coöperation between the operating engineer and the designing engineer is with regard to the adherence to established standards. It may safely be stated that a five to ten percent saving in cost of motors would be effected if a more thorough understanding existed between the operating and designing engineers regarding standards, thus avoiding many unnecessary new designs. The manufacturers of motors are in the business for the purpose of yielding a fair profit to their stockholders but they desire at the same time to do full justice to their patrons, precisely the same as the railway companies. For this reason they cannot consistently expend thousands of dollars yearly in making special designs that do not bring a fair return to either the manufacturer or the railway companies.

The solution of this wasteful practice seems to rest with the railway operating engineers, because as long as competition between the manufacturers is keen (and it should be) there will always be a tendency to vie with each other, in endeavoring to curry favor by agreeing to make any change that individual purchasers may wish to try out. Since it is obvious that ultimately the cost of such special designs must be absorbed through sales prices, it appears to be a pertinent subject for the railway companies through their engineering associations, to have a voice in such matters. This could be done by appointing committees on railway motor standards, who could issue specifications for fixed standards; these standards could be revised from time to time, and in this way the road kept open to continued sane development and improvement. Such standards, when once authoritatively established, would undoubtedly act as a guide to all railway operating engineers in drawing up specifications, and would avoid considerable wasteful expense in special designs that are frequently encountered, and for which no good reasons are apparent.

There is no doubt that considerable progress has been made in railway motor design through the liberal attitude of the manufacturers in introducing various changes in design to meet individual specifications of purchasers. A review of all of the changes made during the past few years discloses, however, the fact that many of them were unnecessary, have proved to be unsatisfactory, and were later abandoned, while many of those that remained and stood the test of time were suggested improvements that were first placed in trial service and properly developed before being adopted on large numbers of motors as a standard.

MOTOR FRAME

The principal conditions to be considered in the design of the motor frame are safety of operation, ruggedness, light weight, uniformity and accessibility for inspection and repair. As a rule it is not very difficult to make the frames sufficiently strong mechanically. On the other hand, it is necessary as a rule, on account of the difficulties experienced in making steel castings, to cast certain sections of the frame heavier than would be necessary for reasons of strength. This in turn is one difficulty opposing attempts for getting light weight. It appears, therefore, that a change to some material which permits a construction as light as permissible from the strength point of view is a step in the right direction. The pressed steel railway motor described in this issue should, therefore, be considered as a very important development. The

weight reduction possible with this motor is further increased due to the fact that the material is better in its magnetic qualities. Aside from using better material for the magnetic sections of the frame, the condition of light weight might further be fulfilled by designing the motor electrically for a small main flux with the use of a comparatively strong armature. This, however, can be done within certain limits only, because going to the extreme in this direction leads to difficulties in electrical design with regard to motor

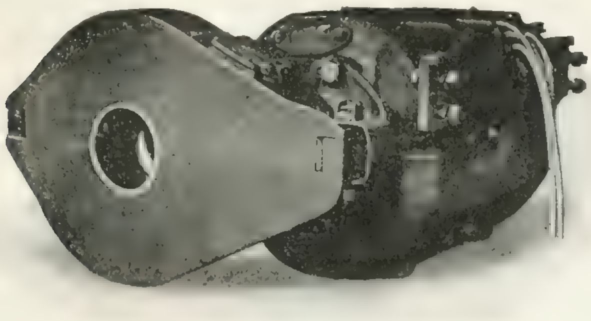

FIG. 4—BAR TYPE OF SUSPENSION FOR RAILWAY MOTORS

flashing, etc., as has been demonstrated by some designs of light weight motors.

The condition of uniformity unfortunately cannot be fulfilled to a very marked degree with steel castings, since certain variations in this direction are unavoidable on account of the somewhat variable thickness of steel castings and a certain amount of blow holes. The variations will naturally lead to some variation in the motor weight, as well as certain variations in motor speed. While these conditions could be improved by the use of cast iron or malleable iron, the lower magnetic qualities and mechanical strength make the use of these materials practically impossible. It seems, therefore, that here again the pressed steel construction represents the only hope for improved conditions.

The condition of accessibility for inspection and repair may best be fulfilled by the use of a split motor which can be opened up underneath the car and taken apart for inspection and repair, but here again other conditions must be considered at the same time and the best compromise chosen. It is of little advantage to adopt a motor which can easily be repaired if this necessitates the use of a construction causing additional repairs. No matter how good the design of the split frame may be it will always require inspection and maintenance of the bolts, which are eliminated in the box frame. This fact should be kept in mind by the operating man. His decision in the matter will, of course, largely be governed by his own shop facilities for removing the motor from under the car. As a rule, the better equipped large railway barn finds the box type frame more advantageous, while other properties which do not have adequate shop facilities for handling box frames often fare better with the split frame motor. These latter remarks apply more particularly to standard motors of the smaller ratings. In the larger ratings, the split construction is not only practically impossible on account of space limitations, but its use would also be exceedingly undesirable because the larger strains in such motors make the design more difficult. In some of the motors recently designed for small wheels the split construction is also practically impossible on account of space limitations.

With regard to safety, the principal point to be considered in the frame design is to provide means to prevent the dropping of the motor out of the truck. In case of bar suspended motors, the bar is held to the motor by heavy bolts but it is advisable to have certain frame portions extending over the bar to carry the motor weight in case the bolts fail, as shown in Fig. 4. In case of nose-suspended motors, there should always be some extra safety lugs for emergency, as shown in Fig. 5, to catch the motor in case the nose breaks. This is advisable since no matter how strong the nose is made there is always a chance for flaws and blow holes as long as cast steel is being used. Another feature to be considered in the frame design is the provision of drain holes of sufficient size in the bottom of the frame. While such holes, especially in enclosed motors, increase the chance for getting water into the motor, their use seems nevertheless desirable. As a rule it is impossible in enclosed motors to keep water altogether out of the motor because whenever the car is allowed to stand over night in the barn there may be a certain condensation inside of the motor, and this water, if kept in the motor, will cause much more damage than whatever water might temporarily get in through the drain holes and flow right out again. The drain holes are

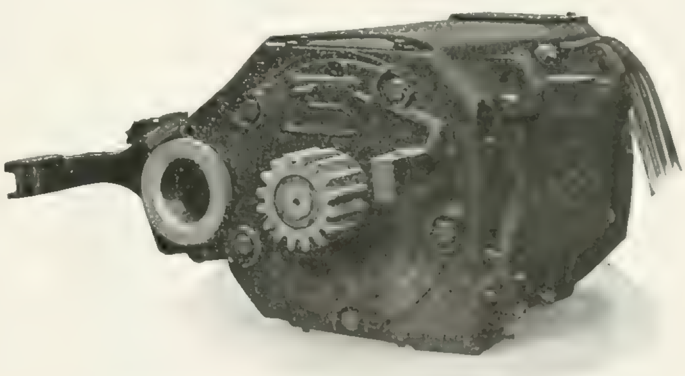

FIG. 5—RAILWAY MOTOR SUSPENSION OF THE NOSE TYPE

also advantageous because carelessness on the part of the men oiling the bearings often causes oil to get into the motor, which would have a harmful effect on the insulation of the field coils if retained. As a matter of course the frame should be provided with lifting bails, hooks or some other means for facilitating the handling. For the rest, the design of the frame requires, as a rule, much time and effort to get sufficient space on the inside for the poles and field coils with sufficient clearance between these parts to permit an easy removal in case of repair.

(To be continued)

The Pittsburgh, Harmony, Butler & New Castle Railway

BEAVER VALLEY LINE

G. T. Twyford

Master Mechanic,
P. H. B. & N. C. Railway Company

THE PROJECTION of the Harmony Route passenger and freight system of interurban service into the Beaver Valley, at last closes a territorial gap which has been the burial ground of much previous engineering and finance. It connects up the prosperous counties and county seats of Allegheny, Butler, Beaver and Lawrence, together with the Mahoning and Shenango Valleys and their allied interests, and opens up a previously unserved territory south of the Beaver river. Lawrence county,

FIG. 1—MAP OF PITTSBURGH, HARMONY, BUTLER & NEWCASTLE RAILWAY

together with the Mahoning and Shenango Valleys, is now in direct traction touch with the Beaver and Ohio Valleys, and Butler county and the territory to the north and south are now relieved from the circuitous and tortuous route of the Ohio river by this direct service through Elwood City to the south. The territory lying south of the Beaver river will now receive the attention of electric traction as the topography of the country toward Darlington, Columbiana, Salem and East Liverpool, and west to Youngstown presents every inducement for further extension of the Harmony Route System. Hourly service between New Castle and Beaver will be maintained over the new division.

The Beaver Valley branch is not an interurban system, such as are most of the electric roads in this section, but it is built under steam railroad construction, with much of its own right-of-way, low grades, long radius curves, steel bridges and concrete masonry. Many obstacles caused by the natural topography of the country had to be overcome in this project, such as the construction of the Beaver River bridge, which had to span the four-track system of the New York Central, the double-track system of the Pennsylvania Railroad, and the Elwood Connecting Railroad, as well as the Beaver River itself and the future route of the Erie Canal.

SUB-STATION

The sub-station for this branch of the Harmony Route System is located at Koppel, about four miles from Elwood City, and is to be utilized, not only for electrical apparatus, but also as a waiting station for passengers and as a freight station.

There is installed in the station at present one 550 k.v.a. three-phase 13 200 volt transformer and two 250 kw three-phase, 60 cycle, 600 volt rotary converters mounted on the same bedplate, connected in series to give 1 200 volts direct current. The station is provided with a three-panel switchboard, low-equivalent lightning arresters, disconnecting switches and choke coils, with Burke horn gap lightning arresters and choke coils on the outside of the building.

ROLLING STOCK

The new cars for this system consist of five combination passenger and baggage cars and one freight car. The principal dimensions and weights of these cars are:—

Length over all, 47 ft. 2 in.
Width over all, 8 ft. 2.5 in.
Distance between truck centers, 24 ft.
Truck wheel base, 6 ft. 6 in.
Diameter of wheels, 33 in.
Weight of car body, 19,845 lbs.
Standard trucks, weight each, 10 270 lbs.
Four motors, including gear and gear case, 14 480 lbs.
Control equipment, including wire and conduit, 4 146 lbs.
Air brake equipment, 2 501 lbs.
Hand brake equipment, 250 lbs.
Heaters, 1 450 lbs.
Miscellaneous, 4 011 lbs.
Average passenger load, 4 000 lbs.
Total weight, 67 187 lbs.
Seating capacity, 64 passengers.

The electrical equipment consists of quadruple equipments of Westinghouse 333 E 3 commutating-pole motors, rated at 115 horse-power 600 volts, with a gear reduction on the passenger cars of 57 to 21 and on the freight car of 61 to 16. The type HL, non-automatic control equipment is arranged to give full speed on the 600 volt as well as on the 1 200 volt sections with an acceleration which is exceptionally smooth.

FIG. 2 — TYPE OF PASSENGER CAR USED ON THE P. H. B. & N. C. RAILWAY

All of the control apparatus operated by the motorman is located in the cab of the car, as shown in Fig. 4, with a view to making all switches as convenient as possible. The control, light and compressor switches are all located on the frieze board just over the car window, in easy reach of the motorman. A cabinet is built in the cab on the right side of the motorman, and contains the main knife switch in the trolley circuit; three six ampere fuses for the control and lighting circuits; the main change-over switch; the main motor cut-out switch; and the protective cutout switch and telephone. The protective cut-out switch is a special switch which operates automatically and clears the control and light circuits, in case the motorman should go from the 600 to the 1 200 volt trolley and fail to throw the change-over switch to the 1 200 volt position. The motors are so connected that the motor cut-out switch cuts out the motors in pairs of *1* and *3* and *2* and *4*. The function of the change-over switch is to connect two motors in series for 1 200 volt operation and in multiple for 600 volt operation. It also connects the different steps of the starting resistance in parallel for 600 volt operation. The master controller is of the hand-operated type,

FIG. 3 — INTERIOR VIEW OF CAR
Showing lighting and seating arrangements.

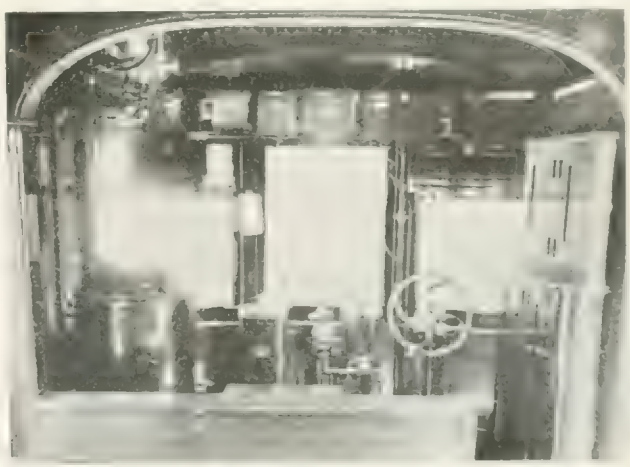

FIG. 4 — [illegible]
Showing location of master controller, air brake equipment and switches

with dead man's feature and has five points for series and four points for multiple operation of the motors.

A great step in advance has been made by the elimination of the dynamotor, using in its place a specially designed resistance of 640 ohms. The

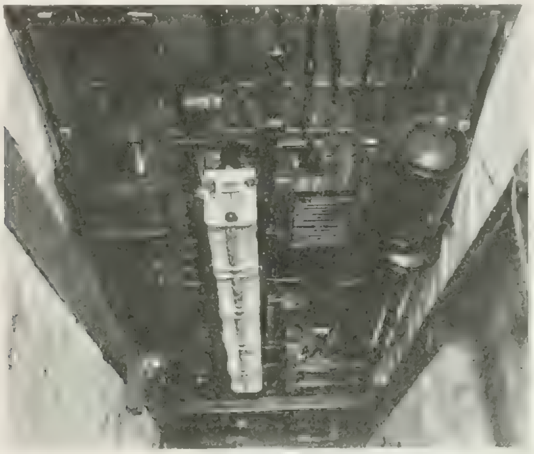

FIG. 5—VIEW UNDER THE CAR
Showing the location and method of mounting the equipment, including control, grid resistors, air tanks and piping, conduit, etc.

total resistance of 640 ohms is in series for 1 200 volt operation, and when the main change-over switch is thrown to the 600 volt position, 320 ohms are shunted, leaving 320 ohms in series for 600 volt operation. The control is then shunted across a portion of this resistance so as to give approximately 100 volts over the control magnets at all times. The headlight resistance is of the same type as that for the control and has a total resistance of 234 ohms and a current capacity of 4.4 amperes. The headlight resistance also has the same provision in the change-over switch for 600 volt operation as the control resistance.

A unique lighting system has been adopted by using 15 and 25 watt tungsten lamps. The 36 lamps comprising the car lighting system are divided into three circuits of 12 lamps in series for 1 200 volt operation, and these circuits are separated by the change-over switch, to connect six lamps in series

FIG. 6—LOCATION AND MOUNTING OF CONTROL EQUIPMENT

for 600 volt operation. The lamps are located in the circle of the roof directly over the back of each seat, and are equipped with elliptical pressed prism glass shades. All light circuits are made with cable wire, insulated for 2 500 volts, and all car wiring to the lamps is carried in a separate groove, cut in the back of the frieze board just over the car window.

The control wiring is carried through steel enamel conduit in straight runs and the main motor wiring is taken care of by means of two transfer boxes which are connected together by five straight runs of two-inch steel conduit. These transfer boxes are three-eighths inch castings and are made in sections to adapt them to the underframing of the car body, the sections being bolted together. A water-tight joint is made possible by using a flange and machined joint.

The first transfer box, which is made in three sections, is located directly under the cabinet in the cab and takes all the main motor wiring from the change-over and cut-out switches, and also the trolley cable and distributes them through the two-inch conduit runs to the main transfer box.

The main transfer box is made in five sections all bolted together. The first section takes the two-inch conduit runs from the box located in the front of the car. The second section is at right angles to

FIG. 7—SPECIAL VENTILATOR DOOR
Designed to cause a movement of air within the car from rear to front.

the first and takes one two-inch outlet from the line switch. The third and fourth sections are all in line with the second section, and parallel with the sills of the car body. These sections take the two-inch outlets from the switch group and reverser. The fifth section is at right angles to the fourth, crossing over under the two center sills of the car body, and takes the four 1.5 inch conduit runs from the motors on either side of the center sills. This transfer box, when bolted together, makes a complete unit which takes care of all the main wiring from all four motors, all the switches, the reverser and the starting resistance.

The connections made from th^ main transfer box to the line switch, switch group and reverser are made through fiber tubing, two inches in

diameter and three-sixteenths of an inch thick. This fiber tubing is boiled 24 hours in paraffine which makes it impervious to water and increases its life. The fiber insulates the switches and reverser, from the transfer box, which of course is grounded. All 1 200 volt apparatus is insulated from the hangers by means of a special insulated bolt, with a porcelain insulator.

The cars have a seating capacity of 58 passengers, and special provision is made to seat 64 passengers by placing folding chairs in the baggage compartment. The maximum seating capacity has been obtained by eliminating the partition between the smoker and the main section of the car, the first three pairs of front seats being reserved for smoking. This scheme of seat arrangement has been made possible by the system of ventilation used in these cars, which was originated by Mr. Harry Ethridge, superintendent of the Harmony Route System. The ventilators are located in the two front side doors in the baggage compartment, as shown in Fig. 7. When a car is in motion there is produced an unbalanced air pressure between the rear and front of the car, and if these pressures are allowed to neutralize each other there will be a continuous circulation of air from the rear to the front of the car, and out through the side ventilators. The circulation of air increases to a maximum as it approaches the ventilator in the front of the car. In a car equipped with this system of ventilation, the smoke from the smoking section passes directly in front of the smoker and out through the car ventilator.

Some Railway Operating Results

H. L. Kirker

THE REAL TEST of any railway installation is continuous operation over a long period. The following resumé of the operating conditions on a number of prominent single-phase railways gives an interesting insight into the results being secured in actual practice.

THE INDIANAPOLIS & CINCINNATI TRACTION COMPANY

The Indianapolis & Cincinnati Traction Company built the original single-phase road in the United States. It is now in its tenth year of operation, furnishing a high speed interurban service at a low operating cost, and its revenues are more than sufficient to pay its operating expenses and fixed charges. Since this road has long ceased to be a novelty, its operating record is somewhat overshadowed by the publicity now being given to high voltage direct-current roads, and a reminder is in order. We are accordingly citing some of the Indianapolis & Cincinnati Traction Company's pertinent operating statistics. For a clearer appreciation of the figures a few of the physical facts relative to this important interurban road will be recalled.

The Indianapolis & Cincinnati Traction Company's lines are made up of two routes, as follows:—

Indianapolis Terminal to Connersville	58 miles
Indianapolis Terminal to Greensburg	49 miles

The two routes use a common track from the Indianapolis Terminal to the junction, a distance of 4.3 miles. Three miles of this distance is double track with 500 volt direct-current trolley. The rest of the route is single track with 3 300 volt single-phase trolley. There are 100 miles of single-phase track. All the motors operate on both direct and alternating current.

The motor equipment is as follows:—

18 combination passenger and baggage cars equipped with four 100 hp motors.
4 express and freight cars equipped with four 100 hp motors. The combination cars have a seating capacity of 54 and weigh 51 tons without load.

The passenger service is as follows:—

Local trains	50 per day
Limited trains	21 per day
Dispatch trains	7 per day
Total trains	78 per day

All the schedules are severe. Some of them are as follows:—

Indianapolis Terminal to Greensburg (49 miles)

Local trains	24.6 miles per hour
Limited trains	29.6 miles per hour
Dispatch trains	33.6 miles per hour

Indianapolis Terminal to Connersville (58 miles)

Local trains	25.2 miles per hour
Limited trains	32.7 miles per hour
Dispatch trains	38.8 miles per hour

Indianapolis Terminal to Rushville (40.9 miles)

Local trains	[illegible]
Limited trains	31.5 miles per hour
Dispatch trains	37.1 miles per hour

Junction to Dagler (intermediate stretch between Indianapolis and Rushville 35.5 miles)

Local trains	[illegible]
Limited trains	[illegible]
Dispatch trains	53.5 miles per hour

Maximum speed, 60 miles per hour

TABLE I.

Operating Expenses	1911.	1912.	1913.	1914.
I—Way and structures, cents per car mile.	2.856	3.536	3.677	[illegible]
II—Equipment, c. p.c.m.	3.117	2.685	3.474	3.362
III—Traffic, c. p.c.m.	0.226	0.158	0.134	0.090
IV—Transportation, c. p.c.m.	7.360	7.239	7.666	7.978
V—General and misc., c. p.c.m.	3.867	3.896	4.196	4.391
Total operating expenses	17.426	[illegible]	19.147	19.137

Some of the operating expense accounts were as follows:

Acct. No. 30, Maint. of power plant equipment	[illegible]	[illegible]	0.602	0.051
Acct. No. 31, Maint. of substation equipment	[illegible]	[illegible]	0.017	0.099
Acct. Nos. 32-35, Maint. of all cars	[illegible]	[illegible]	0.829	0.996
Acct. Nos. 36-37, Maint. of elec. equip. of all cars	[illegible]	[illegible]	[illegible]	1.792
Acct. Nos. 49-59, Power.	[illegible]	[illegible]	3.020	3.031
Acct. 62-63, Misc. car service, employees and expenses	[illegible]	[illegible]	[illegible]	0.426
Acct. Nos. 66-67, Carhouse employees & expns.	[illegible]	[illegible]	[illegible]	0.687
Kw-hr. per car-mile at power plant	[illegible]	5.11	[illegible]	[illegible]

The car mileage was as follows:

Passenger car miles	1 438 697	1 397 468	1 351 698	1 344 158
Freight car miles	139 617	138 570	115 159	120 502
Total car mileage	1 578 314	1 536 038	1 466 857	1 464 660

The revenues were as follows:

Pass. & Exp. car revenue	$405 572	[illegible]	[illegible]	[illegible]
Freight revenue	39 040	35 134	36 497	38 753
Other revenue	982	1 064	[illegible]	[illegible]
Total operating revenues	$445 594	[illegible]	451 415	$460 138
Total operating expenses	$275 042	[illegible]	[illegible]	[illegible]

These speeds necessarily make heavy drafts on power. The power consumption at the power plant, however, is not abnormal. The average for the last four years is 5.12 kw-hr. per car-mile and the cost 3.33 cents per car-mile. This cost figure is the sum of the power plant and substation operating expense. Inasmuch as the installation is single-phase the substations are merely transformer substations; the power cost is practically all power plant cost. The high speeds are also reflected in the maintenance cost. The average figure for the

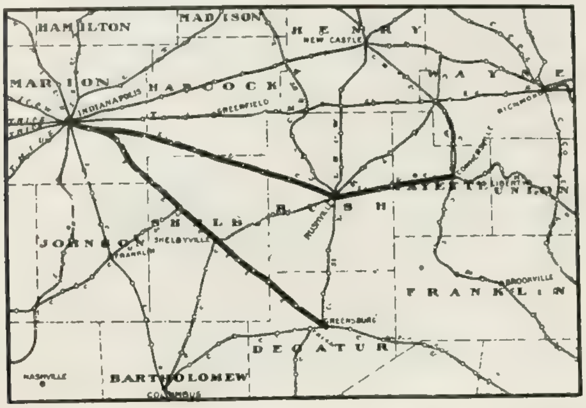

FIG. I—MAP OF INDIANAPOLIS AND CINCINNATI TRACTION COMPANY'S LINES

last four years for *Group II, Maintenance of Equipment,* is 3.21¢ per car-mile. The total operating expense for the same period, however, averaged but 18.8¢ per car-mile. The four year summary of the operating results is given in Table I.

The calendar year 1913 was a hard year for the Traction Company. It was a year of flood and strikes. First came the disastrous March flood that submerged equipment and washed out tracks. Then came the trainmen's strike in August and then the linemen's strike in September. Finally the strike on the city lines in Indianapolis in November prevented the Traction Company's cars from entering the city. This mixed up year affected the Company's showing for both 1913 and 1914. But as shown in Table II the average operating expense per car-mile for the last four years on the Indianapolis & Cincinnati Traction compares favorably with the operating expense of a number of direct-current interurban roads.

TABLE II—AVERAGE OPERATING EXPENSE PER CAR-MILE FOR SEVERAL TYPICAL INTERURBAN ROADS.

Indianapolis & Cincinnati Trac. Co., single-phase, 3 300 volts....	18.8 c. p.c.m. (Avg. 1911-14)
Washington, Baltimore & Annapolis Electric R. R., 1 200 volt trolley & conduit................	19.9 c. p.c.m. (Avg. 1911-13)
Pittsburgh, Harmony, Butler & New Castle Rwy. 1 200 volt trolley	19.3 c. p.c.m. (Avg. 1911-13)
Aurora, Elgin & Chicago R. R., 600 volt trolley and 3d rail....	18.1 c. p.c.m. (Avg. 1911-13)
Ft. Dodge, Des Moines & Southern R. R., 1 200 volt trolley....	20.7 c. p.c.m. (1913)
Oregon Electric Rwy., 1 200 volt trolley	29.7 c. p.c.m. (Avg. 1911-13)
Central California Trac. Co., 1 200 volt 3d rail............	27.0 c. p.c.m. (Avg. 1912-13)
Scioto Valley Traction Co., 600 volt 3d rail..................	20.7 c. p.c.m. (Avg. 1910-11 & '13)
Otsego & Herkimer R. R., 600 volt trolley..................	30.1 c. p.c.m. (Avg. 1910-13)
West Penn Railways, 600 vollt trolley	22.5 c. p.c.m. (Avg. 1910-13)

The above figures have been derived from annual reports to the Interstate Commerce Commission. They bring out a fact not generally known, viz., that the operating expense per car-mile on the Indianapolis & Cincinnati Traction, the original single-phase road in the United States, is lower than the operating expense on a number of typical direct-current interurban roads of both the 600-volt and the 1 200-volt class. The ten years' record of the single-phase equipments on the Indianapolis & Cincinnati Traction lines is a convincing guarantee of the ability of the single-phase railway motor to stav put.

ROCK ISLAND SOUTHERN RAILWAY

THE Rock Island Southern Railway is more than an interurban line. It is a real railroad, and its economic location is good, especially as regards freight traffic. It is a north and south line in western Illinois that taps several east and west steam roads. A glance at the map shows that it has no competition in its territory. It runs through a rich agricultural country and opens up a new coal field. The main line extends southerly from Rock Island to Monmouth, Ill., a distance of 50 miles. For 20 miles out of Rock Island the "Southern" uses the Chicago, Rock Island & Pacific tracks. The rest of the route is new construction. At Rock Island the road interchanges traffic with the "Rock Island," the "Burlington" and the "St. Paul." At Gilchrist, 30 miles south of Rock Island, it has a physical connection with the "Burlington." At Monmouth it interchanges with the Minneapolis & St. Louis (Iowa Central) and the "Burlington." Seven miles east of Monmouth, at Cameron, it has a physical connection with the "Santa Fe." A branch line extends to Aledo, six miles, another to Alexis, four miles, another to the Matherville mines, another to the Riddleville brick yards and clay banks and another to the gravel pits near Milan. Altogether there are 60 miles of single-phase track and a mile or two of extensions over which the trolley wire has not yet been strung.

The transportation facilities which this new route furnishes are unlocking the resources of this territory. Stock yards are going in, grain elevators are being built, towns are growing, and diversified industries are springing up. The nimble service furnished by the electric "motors" is the main factor in the development. The steam locomotive with its infrequent three-car local passenger trains and its slow moving local freight trains, could not accomplish such results as the Rock Island Southern is getting. All of the passenger traffic is handled electrically. The freight business on the south half of the line is handled by "motors," as the carbarn is at Monmouth. The freight business on the north half is handled by steam, since the round house is at Rock Island. Steam locomotives are also used in the mine yards and gravel pits and at several other points where the trolley construction has not been completed.

There are six passenger cars and two freight "motors," six steam locomotives and 213 freight cars. The passenger cars are equipped with four 100 horse-power, single-phase motors, and the freight "motors" are equipped with four 125 horse-power, single-phase motors. The passenger cars are geared for a free running speed of 45 miles per hour and are operated at a schedule speed of 22 miles per hour. The freight "motors" can handle a 330 ton train on the ruling grades and 500-ton trains on the rest of the line. The most of the steam locomotives are engines that were used during the construction period. They are employed primarily in the coal traffic and necessarily on the track extensions over which the trolley wire has not yet been strung.

The road is a young one—barely four years old. Steam service was inaugurated during the summer of 1910 and electric service in December of the same year, when the power plant was put in commission. The initial service was necessarily crude, for the construction work was far from complete when the road began to furnish transportation and take in revenue. There were troubles, both physical and financial. Most new roads have their troubles during the lean years of early operation. It often happens that sufficient provision

has not been made to safeguard the investment during the time the new road is not self-supporting. The Rock Island Southern, however, has more than paid its operating expenses from the start.

The four year statement, year ending June 30, 1914, is given in Table I:—

TABLE I.

Items	1911	1912	1913	1914
Freight revenue	$ 71 913	$108 540	$165 707	$137 398
Passenger revenue	55 830	117 217	138 476	173 696
Other revenue	6 292	5 630	10 223	14 372
Total revenue	$134 035	$231 387	$314 406	$325 366
Operating expenses.....	$100 236	$163 632	$174 209	$202 347

This statement effectively refutes various gloomy forecasts made for the road. The first popular prediction was that

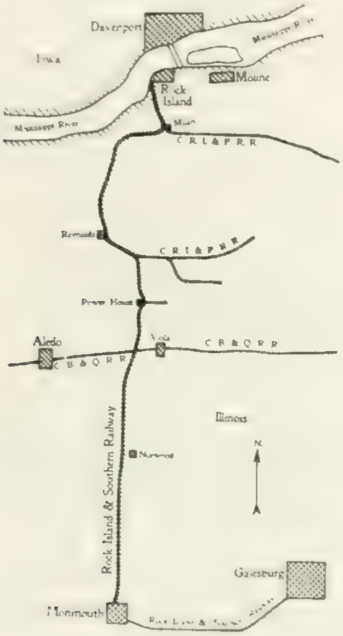

FIG. 2 ROCK ISLAND SOUTHERN RAILWAY AND CONNECTING LINES

the promoters could never build the road. As the road neared completion the forecasters decided that the promoters could never operate a single-phase road anyhow. As operation began to settle down to the present routine the prophets took the final stand that the operating expenses would swamp the property. The four years record discredits all critics. The fact is the road is a live wire property with energy behind it As already pointed out its economic location is good. The 11 000 volt trolley and the single-phase equipment furnish a simple and effective motive power. The promoters took a long look ahead before they made their fundamental decision on motive power. Having made their decision they proceeded to finance the property, put in the road and operate it. At the end of four years' operation the same people continued to run the road. The property is in good physical shape and is growing. The service is good, the traffic is good and the future prospects are good.

The Rock Island Southern is a practical example of high voltage railroading. Here is a 50 mile route with the power plant at the middle of the line and a single trolley wire between terminals, without a feeder and without a sub-station. With 11 000 volts on the trolley, a 500-ton train can be handled at the end of the line without a material drop in pressure at the train. The motors themselves are fed from the secondary of the transformer on the car at the maximum voltage of 500—the same voltage that is used in city street car service. Moreover, these motors and the control are insulated from the ground. Insulation failures and flashing are accordingly reduced to a minimum. The control is simple. These three facts—low voltage motors, non-grounded motor circuits and simple low voltage control—all combine to minimize equipment failures.

Here is the main motor failure record for the last four years:—

1910

None

1911

September 14th—Locomotive burnt out one armature on account of low bearings. Armature rubbed field poles.

December 24th—Passenger car armature burnt out. Car had been overloaded in freight service.

1912

February 6th—Locomotive armature split a pinion. Armature ran away, destroying armature winding and field winding.

February [illegible]—Passenger car armature [illegible]. Car had been overloaded in freight service.

March 12th—Locomotive armature burnt out. Same armature had had pinion trouble a few days previous to burnout.

March 28th—Passenger car armature burnt out on account of neglected broken brushes. Failed at the end of 3 days of hard service, with no time allowed for inspection.

October 21st—Locomotive armature broke shaft at pinion. Armature ran away, destroying armature winding and field winding.

November 23d—Passenger car armature, removed to have commutator turned, found to be grounded.

December 15th—Passenger car armature found to be grounded at regular inspection.

1913

September 1st—Locomotive armature winding destroyed by loose field plate bolt.

October 3d—Passenger car armature burnt out on account of bent shaft.

1914

None to date—August 31st.

The total number of main motor failures in four years is eleven. Five of these were due to mechanical causes. During the years 1911-12 the passenger cars did a great deal of freight work. They hauled freight cars over the line and did switching work at the stations. Had the single-phase equipments not been exceedingly robust the service would have been disastrous to the motors and control.

The simplicity of the equipment is emphasized by the fact that no corps of electric experts is required to keep the "motors" rolling. The general superintendent is a steam man—a transportation man who, previous to his coming to this property, had no experience with electric motive power. The master mechanic is a steam man, also without previous electric experience. The dispatchers are steam men, likewise the roadmaster. The lineman, of course, is an electrical man. The man who has run the power plant for the last three years is a steam man who has acquired a working knowledge of electrical machinery. Necessarily, some of the men at the car barn are electrical men, but the bulk of the work at

FIG. 3 [illegible]

the barn is mechanical. Keeping the motors and control in commission is by no means the most expensive part of the barn work.

Steam road men watching the performance of the "motors" on the Rock Island Southern cannot escape being impressed with the simple solution which high voltage trolley and low voltage motors and control give for steam road branch line work. These steam men see that this motive power is easy to apply and easy to operate, that it is simple and reliable, that it can handle a heavy freight train as easily as it handles a single car passenger train, and assuming that

power can be bought at the trolley as it actually is in the case of the Rock Island Southern—they see that the investment practically narrows down to the trolley, the "motors" and a modest addition to the shop and stores. Eliminating the power plant, the transmission line, the substations and the feeders, brings the investment down to a point where steam road managements can begin to take interest in the subject of branch line electrifications. Then with examples of satisfactory performance such as the Rock Island Southern "motors" afford them the steam men can give branch line electrification serious attention.

One of the most satisfactory features in connection with the Rock Island Southern is the attitude of its operating force—practically all steam men—towards electric motive power. Ask any of them how the electric trains are running and their answer is, in the language of Joe, "O. K. and on time."

NEW YORK, WESTCHESTER & BOSTON RAILWAY

THE New York, Westchester & Boston Railway is a single-phase suburban road. It extends from New York (Harlem River) through Mount Vernon to New Rochelle, a distance of 12.2 miles. A branch extends from Mount Vernon to White Plains, a distance of 9.2 miles. Mount Vernon is 10.3 miles from Harlem River.

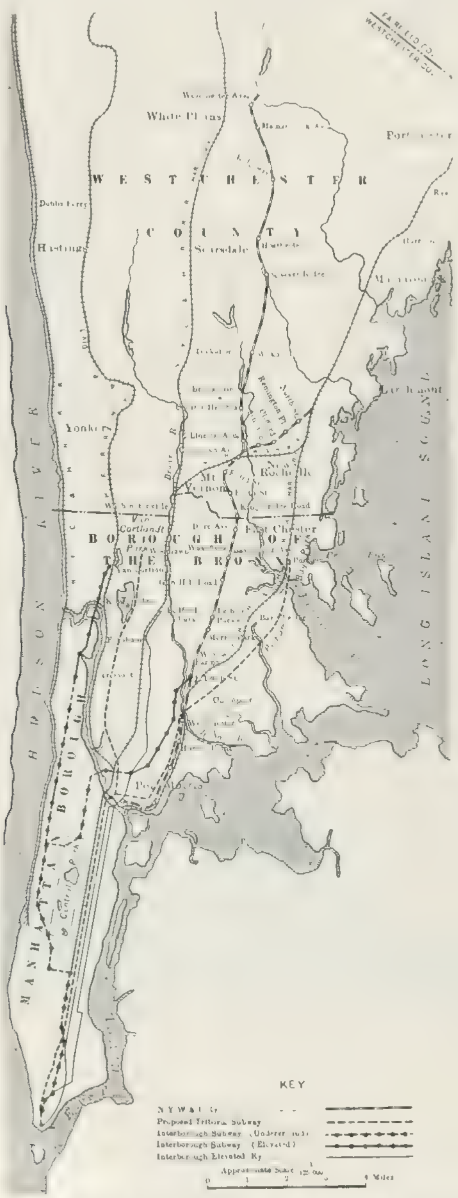

FIG. 4—NEW YORK, WESTCHESTER & BOSTON RAILWAY

The road is two and four-track and is controlled by the New York, New Haven & Hartford Railroad. The trolley pressure is 11 000 volts. The motors are straight single-phase. Electric service was inaugurated May, 1912.

The passenger rolling stock consists of 30 cars weighing 60 tons each without passenger load. Each car is equipped with two 175 hp single-phase motors and multiple-unit control. Twenty-eight of the cars are passenger cars with a seating capacity of 78. The other two are combination passenger and baggage cars.

In the Harlem River—White Plains service, about half of the trains are local all the way through. These trains have a schedule speed of 25 miles per hour and average 0.89 of a mile between stops. The rest of the trains in the White Plains service are express between Harlem River and Mount Vernon and local the rest of the way. These trains have a schedule speed of 31.7 miles per hour from terminal to terminal and average 1.78 miles between stops.

About half the New Rochelle trains are local all the way through. The schedule speed of these local trains is 21.6 miles per hour and they average 0.68 of a mile between stops. The rest of the New Rochelle trains are express between Harlem River and Mount Vernon and local the rest of the way. The schedule speed of these trains is 34.6 miles per hour from terminal to terminal and they average 1.75 miles between stops.

The power consumption averages about 4.5 kw-hr. per car-mile at the car for the whole service, or about 69 watt-hours per ton-mile at the car for the loaded car weighing 65 tons. This figure is the total power consumption at the car. In addition to the power consumed by the main motors, it includes light, heat, auxiliaries and all losses.

The New York, Westchester & Boston is making an extraordinary record in the matter of reliability of service. During the year ending June 30, 1914, there were but 78 delays and three annulments chargeable to the electric motive power out of a total of 73 460 trains operated. The record was as follows:—

Total number of trains run (electric)	73 460
Total number of delays chargeable to electric motive power	78
Total minutes delay chargeable to electric motive power	568
Average number of minutes per delay	7.27
Total number of annulments chargeable to electric motive power	3

The 78 delays and 3 annulments were distributed over the 12 months as follows:—

	Delays	Avg. Min.	Total Min.
July 1913	10	13.5	135
Aug.	4	10.8	43
Sept.	5	6.4	32
1 annulment.			
Oct.	6	5.5	33
Nov.	9	7.4	66.5
Dec.	2	1.5	3
Jan. 1914	5	2.5	12.5
Feb.	15	7.85	118
1 annulment.			
Mar.	12	4.85	58
Apr.	6	7.8	47
May	4	5.0	20
1 annulment.			
June	0	0	0
	78	7.28	568.0

This record includes all delays chargeable to electric motive power. It is the total of all delays occasioned by car equipment failures, line failures, power plant failures and man failures. Of the 78 delays, but three were due to motor trouble. These three motor trouble delays to-

taied but nine minutes. Thirty were chargeable to pantagraphs and 18 to brake equipment. The others were due to power failures, control troubles, man failures and miscellaneous trouble. This performance on the part of the New York, Westchester & Boston Railway is another proof of the applicability of the high voltage single-phase trolley and the low voltage single-phase motor and control to railroad work.

MULTIPLE UNIT TRAIN SERVICE ON CHICAGO, LAKE SHORE & SOUTH BEND RAILWAY

The C. L. S. & S. B. Railway extends from South Bend, Ind. [illegible] Through passenger service is furnished to Chicago over the Illinois Central tracks. The Illinois Central locomotives haul the interurban trailers between Kensington Station on the C. L. S & S. B. near Pullman, and the Illinois Central's Randolph Street Station in Chicago. The motor equipment is single-phase. The trolley pressure is 6 600 volts.

ANOTHER demonstration of the significance of high trolley voltage was made by the Chicago, Lake Shore & South Bend Railway last July 4th. On the 4th this road handled four times its normal traffic and handled it without change of schedule. It did it by increasing the size of its regular trains. The "South Shore," as the road is known locally, ran holiday trains of a size that would flounder a direct-current trolley road. It handled these trains with ease and promptness. The biggest train was made up of 7 multiple-unit cars and weighed about 330 tons. The average size of train for the day was three cars. Altogether 54 trains were run. The sizes were as follows:—

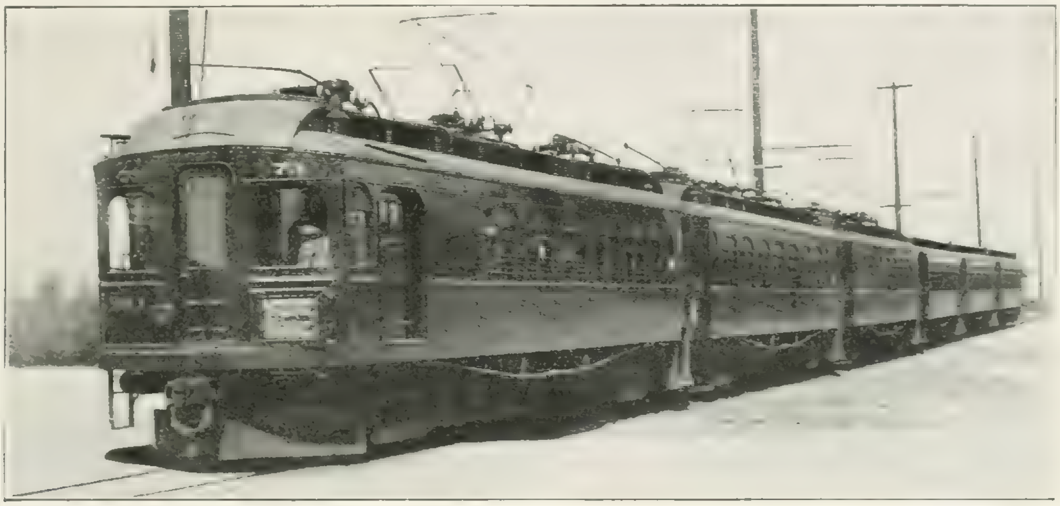

FIG. 5—SIX CAR MULTIPLE-UNIT TRAIN ON THE CHICAGO LAKE SHORE & SOUTH BEND

4	trains—	1 car
2[illegible]	trains—	2 cars
13	trains—	3 cars
[illegible]	trains—	4 cars
4	trains—	5 cars
1	train—	6 cars
2	trains—	7 cars

Normally the trains between South Bend and Gary (59 miles single track) are single car, and between Gary and Pullman (17 miles, double track), they range from one to three cars.

The relative size of the holiday traffic peak is indicated by the following table:—

	July 4, 1914	July 1, 1914
Total number of passengers carried.....	15 260	[illegible] 475
Total car miles....	8 150	3 399
Average fare per passenger	30c	12.25c

Note that the average fare on the 4th was more than double the normal fare (which means the distance traveled per passenger on the 4th was more than double the normal distance traveled per passenger) and that the total car-miles on the 4th was about double the normal daily passenger car mileage. Twice the normal number of passengers traveling twice the normal distance gave a volume of traffic four times the normal. All the rolling stock was on the road. The service was excellent. There was no confusion. There were no accidents. There were no failures of electric equipment. One car developed a hot box. One car broke a journal brass. That was the extent of the troubles. There were no second sections. Solid multiple-unit trains did the work. There was no slump in trolley voltage—no drop in speed. The number of train orders issued was exceedingly small. Forty-five of the 54 trains reached their destination on time.

The 4th of July performance of the Chicago, Lake Shore & South Bend is characteristic of the all year round performance on this road. The trains move with a remarkable regularity. The yearly average shows that more than 97 percent of the trains reach the terminals on time. Multiple-unit trains are built up on a moment's notice. During the excursion season, trains of 5, 6 and 7 cars are

FIG. 6—CHICAGO, LAKE SHORE & SOUTH BEND RAILWAY

a common occurrence. The ability to handle big multiple-unit trains on the C. L. S. & S. B. and the ability to arrive on time is due to two facts, viz. the high voltage trolley and the management. The high voltage trolley makes the performance possible. The management makes it a fact.

Methods of Load Dispatching

THE SYSTEM OF THE PUBLIC SERVICE ELECTRIC COMPANY OF NEW JERSEY

J. T. Lawson
Chief Operator

THE Public Service Electric Company consists of three main divisions over the state of New Jersey—Northern, Central and Southern, according to their geographical relation in the state, having load dispatching centers at Marion, Perth Amboy and Burlington, respectively.

The Northern division consists of five active steam-driven central stations with a combined capacity of 112 700 kilowatts and two stand-by steam-driven central stations with a combined capacity of 9 525 kilowatts. These stations are connected through 200 miles of underground cable and 125 miles of overhead transmission lines to thirty-three substations with a combined capacity of 129 050 kilowatts.

The Central division consists of five steam-driven central stations with a combined capacity of 20 000 kilowatts. In this division there are 130 miles of overhead transmission, with practically no underground cable, connecting the stations to 12 substations having a combined capacity of 41 600 kilowatts.

The Southern division consists of four active steam-driven stations with a combined capacity of 19 200 kilowatts and five stand-by steam stations with a combined capacity of 2 440 kilowatts. Four of these stand-by stations will be replaced this year by substations, so that the capacity of this division can be rated at 19 200 kilowatts. Connected to these stations through 134 miles of overhead transmission (practically no underground cable) are 16 substations with a combined capacity of 22 860 kilowatts.

The Northern and Central divisions were recently connected through one of the substations, but their respective load dispatching centers and methods were not changed except that the men worked together regarding their respective divisions, where formerly they were independent of each other.

As the Northern division is the largest in connected apparatus and the amount of business handled, the methods practiced in this division are of the most interest. The other two divisions use practically the same methods, the only difference being in the amount of work and business the dispatchers have to handle.

The load dispatching system was adopted by this Company about ten years ago when the Marion station was built. The reasons for its adoption are probably the same as in all other electric operating companies; growth and extension of business to such an extent that it becomes necessary, for continuity of service, safety of employees and economical manufacture of electric current, to control all operations from a central point. Prior to this time the Company controlled a number of small engine-driven power stations scattered over a territory of approximately 200 square miles, generating alternating current at 2 400 volts for lighting and direct current at 500 volts for railway purposes, operating over feeders of the usual lengths for work of this character. With the completion of Marion the policy was changed and numerous substations were built to take the place of the steam-driven stations, connected by 13 200 volt, 60 and 25 cycle transmission circuits, with Marion as the center; the 60 cycle power being used through static transformers for lighting and power, and the 25 cycle power through rotary converters for railway work. The apparatus for two separate and distinct systems was therefore housed under the same central and substation roofs. The system at this time was comparatively small, consisting of 30 miles of overhead lines and 70 miles of underground cable. Connected to this network were 39 250 kilowatts in central station apparatus and 32 200 kilowatts in substation apparatus.

Today the system has grown so that the Marion and Perth Amboy men control a system consisting of 200 miles of underground cable and 255 miles of overhead transmission with central station apparatus of 142 855 kilowatts, and substation apparatus of 170 650 kilowatts. The transmission cables have increased in size from No. 4 to 350 000 circular mils, the converters from 300 to 2 000 kilowatts, the transformers from 500 to 3 000 kilowatts and the generators from 3 000 to 25 000 kilowatts. In this period two new central stations and 30 new substations have been built, a number of old stations have been remodeled and work has been started on a new station which will have an ultimate capacity of 150 000 kilowatts. A diagrammatical layout of the system is shown in Fig. 1, from which a general idea of the system can be obtained.

To control this system the load dispatcher situated at Marion has a private telephone system connecting the central stations and substations, which is maintained by the local telephone company. This telephone system enables the load dispatcher to have direct communication with every switchboard operator in the system immediately, without the delay occasioned by talking through a local telephone exchange; an arrangement which is of untold value in times of emergency. Located on the wall of the office in plain view of the operator, as he sits at the telephone board, is a diagrammatic layout of the stations, substations and transmissions system, showing every electrical detail of generators, transformers, converters and all switches and lines. This board can be operated by hand in such a manner that every electrical connection is shown and acts as the load dispatcher's guide to the apparatus and lines. A scheme of white and red plugs is used to indicate apparatus and lines in service, the white indicating those in operation, the red indicating those unavailable for immediate use. As fast as the load dispatcher orders in machines, lines, etc., his assistant plugs up the board accordingly, to show the actual electrical connections, the red plugs being inserted in apparatus and lines which have been ordered out of service by the load dispatcher for repairs or other reasons.

Printed rules for the operation of the transmission system are distributed among the employees. These rules are as follows:—

TRANSMISSION SYSTEM.

The "transmission system" consists of the power houses, sub-stations, transmission lines, cables and apparatus inter-connected for parallel or combined operation.

Load Dispatcher.

(Where the word "Load dispatcher" appears in the following rules and instructions, it is understood to mean "Load dispatcher or his assistant on duty.")

The general operation of the transmission system is under the general supervision of a load dispatcher, reporting direct to the general superintendent of plants. For the initial operation there is a load dispatcher located at the Marion station switchboard. This is connected by a private telephone system with the different stations and substations operating in connection therewith. There are also telephone connections to these stations and sub-stations from the Marion board through the local Public Service exchanges.

All cases of trouble, which are likely to affect the operation of the transmission system, occurring in or reported to the power house or substations, must be promptly reported to the load dispatcher.

Power Stations—Each power station is in charge of a superintendent, reporting directly to the general superintendent. Reporting to the superintendent of a power station are a chief engineer, and three watch engineers, one of whom is always on duty. The watch engineer on duty has immediate charge of the operation of the power house, and is responsible for having sufficient capacity in boilers, turbines, engines and auxiliary apparatus in readiness to carry the normal load, as needed. He will also, under instructions from the load dispatcher, carry such additional load as may be required. Any apparatus to be rendered unavailable shall be first reported to the load dispatcher except in case of emergency, and in such cases shall be so reported immediately thereafter.

The watch engineer must see that the load dispatcher is kept posted as to the number or capacity of generators in service, and the number of boilers under steam or banked. Any trouble, actual or impending, which is likely to interfere with the operation of any station, must be promptly reported to the load dispatcher, so that arrangements can be made with other stations to take over the load where possible.

Sub-Stations—All sub-stations are in charge of the superintendent, reporting directly to the general superintendent.

The sub-station operators will run such rotary converters, static transformers, etc., as may be needed to carry the load, as directed by the superintendent. No 13 000 volt line switches shall be operated without instructions from load dispatcher except in case of extreme emergency, and if so operated the load dispatcher must be promptly advised. The sub-station operator will take instructions from the load dispatcher in regard to switching all outgoing or incoming high tension circuits.

The load dispatcher must be kept advised of the number of rotary converters, static transformers, etc., in operation, the load carried and also, in a general way, as to the condition of the sub-station. Any trouble occurring or impending in the sub-stations must be reported to the load dispatcher as soon as possible, also any trouble occurring or impending near the sub-station on the lines or cables or feeders which may be brought to the attention of the superintendent or operators, must be reported to the load dispatcher immediately. Any apparatus to be rendered unavailable shall be first reported to the load dispatcher except in case of emergency, and in such cases shall be so reported immediately thereafter.

EMERGENCY OPERATING INSTRUCTIONS.

13 000 Volt Lines—In case of trouble on lines or in sub-stations, causing one or more 13 000 volt switches to open, the switchboard operator will report at once to the load dispatcher, giving full information. If any damage has been caused either to apparatus or oil switches, he will report the nature and extent of same and advise the load dispatcher as to the station's ability to carry the load which has been dropped. The load dispatcher will immediately make all possible provision for picking up the load which has been dropped, this matter taking precedence over everything, and after same has been accomplished will proceed to test the lines and locate the trouble, operators and everyone concerned being under his orders for the time being. In all such cases of trouble in power stations or sub-stations, instructions from the load dispatcher will govern.

If tests show there is trouble on a line, endeavor to isolate it by opening all necessary switches. All tests will be made under the direction of the load dispatcher in conjunction with the superintendent.

As soon as possible after trouble occurs, the load dispatcher will notify the superintendent of the division concerned, so that arrangements can be made to assemble men and start repair work. The holding of gangs of men for this purpose is under the discretion of the load dispatcher who is at all times responsible for the promptness of locating faults on cables and lines, and all concerned must work under his directions until fault is definitely located, after which the responsibility rests with the cable department.

As soon as repairs have been made on an underground cable or overhead transmission line, the fact is to be reported to the load dispatcher who will be responsible for both insulatioon and phase tests being made before the cable is put in service again.

Sub-Stations—In case of loss of 13 000 volt power on sub-station bus-bars, the sub-station operator will immediately open all the high tension oil switches, leaving the line switches as they are. The operator will next call up the load dispatcher, telling him that he has lost the 13 000 volt power and that all machines, cables and lines are clear from the high tension bus-bars.

General Instructions—In cases of trouble on the outside, and telephone messages of same being received at power stations or sub-stations, definite information should be asked, and the name of the person asking to have the current shut off should be ascertained, also his position in the company. A sub-station operator or power station operator, on receiving such a call will immediately communicate with the load dispatcher who will assume control of the situation. After the feeders have been killed by the load dispatcher, operators must on no account put same in service again without permission from the load dispatcher.

Loss of Telephone Communication—Ordinarily, telephone communication between power stations and substations, and the load dispatcher will be on the private system. In case of failure of the private system use the nearest outside telephone and call through the company's private exchange.

In case of trouble occurring when all the telephones are out of order the following rules will govern: If 13 000 volt switches open at the power station, two minutes will be allowed sub-station operators to clear their busses when power will be thrown on again, or as soon thereafter as power station is ready. If the switch or switches open the second time they shall on no account be closed until communication is re-established, by telephone or otherwise, with the sub-station affected.

RULES TO INSURE SAFETY OF EMPLOYES AND OTHERS.

General Instructions—Visitors will not be allowed in power stations or sub-stations without properly signed permits, delivered to operator or engineer in charge. Visitors will not be allowed on switchboard galleries or in bus-bar chambers of power stations, nor in basements of substations unless specifically so stated on their permit. If a visitor's pass allows him to visit vicinity of high tension work he must be accompanied by a responsible employe of the station or sub-station.

No employe shall touch, either with or without rubber gloves, any switch, current or potential transformer, cable, bus-bar or conductor, or any other apparatus which ordinarily carries current at a potential greater than 700 volts, until he has ascertained positively, and is satisfied that such conductor or apparatus has been disconnected from such potential and properly tagged.

The load dispatcher will keep strict account of the name of the foreman who has charge of the work on these lines, and the lines cannot again be put in service until released by that foreman to the load dispatcher.

A tag must be put at each end of the line and another on the oil switch control at each end of the line, and another on the load dispatcher's operating board. At the same time the load dispatcher notifies the power station and sub-station to tag the line, he will also notify them to open the knife switches in series with the oil switches and at the same time to short-circuit and ground both ends of the line.

When a load dispatcher receives information from the stations or sub-stations, that the lines have been properly short-circuited and grounded, and that the necessary tags and "not clear" cards have been placed, he will release the line to the foreman and at the same time advise him where the tags, short circuits and grounds have been placed.

If an overhead line is to be cut, the foreman in charge of the work must see that short circuits and grounds are placed [illegible] cut, and that the men work between such short-circuits and grounds. This is in addition to the grounds and short circuits placed on each end of the line.

Before starting work on any high or low tension cables, or [illegible] which are supposed to be dead, the foreman in charge of the work must make tests to ascertain if they are dead. Test lamps may be used for low tension work and [illegible] or other [illegible] for high tension work. Foremen must confer with head of department for whom they work in regard to approved methods of testing for potential.

In replacing potential transformer fuses, rubber [illegible] and in addition the fuse must be held in wooden tongs provided for that purpose.

Work on High Tension Lines and Cables—When [illegible] upon any high tension lines, permission must be obtained from the load dispatcher for killing same. After the load dispatcher has granted permission for work on these lines, before the work is started he will arrange with the stations and substations affected for killing same, and will instruct the [illegible], ground and tag the feeders upon which the work is to be done. A standard tag is provided for this purpose.

Upon completion of the work the foreman will inform the load dispatcher either in person or by telephone, stating that the work has been done and that his men are clear of the line. The load dispatcher will then order off the tags and short circuits and grounds.

If the work has been such that there is a possibility of the connections being changed, a phase test must be made before the line is again put in service, together with the usual insulation tests.

In case of two or more gangs of men working on the same lines at the same time, the load dispatcher will observe the same rules toward them all, taking strict account of each foreman separately.

In case of work to be done on the high tension bus or apparatus in either stations or sub-stations, the load dispatcher must be previously informed of such, and he will take the same precautions as regards tagging and grounding as in outside work on the lines. The name of the foreman who has charge of the inside work will be kept and the switches and tags, etc., will not be touched until the load dispatcher receives word from this foreman that he has completed his work, and the bus or apparatus is ready for service. The load dispatcher will then take steps to have the station or sub-station operators put the apparatus again in service. Operators must not put any such apparatus in service without orders from the load dispatcher.

In case of two or more gangs of men working on the inside at the same time, the load dispatcher will observe the same rules toward them all as on the outside lines.

Safety Devices—A complete set of "First Aid [illegible] medicine chests must be kept in each station and sub-station, and superintendents must see that their operators and foremen are drilled in the use of same, particularly in aid to those injured by electricity.

Addresses of Employes—Each employe who is likely to be called on for emergency work, must keep his foreman or superintendent posted as to his residence and the number of the nearest telephone. Foremen and superintendents will see that they have complete lists of the names and addresses of men on whom it may be necessary to call for emergency work.

Analyzing these rules it is seen that a load dispatcher's duties consist of three main things:—

1—Protect workmen by rendering it safe to work on apparatus and transmission lines.
2—Maintain continuity of service.
3—Maintain economical service.

SAFETY TO WORKMEN

As the rules merely outline the methods pursued, it is in order to outline more clearly the manner in which the load dispatchers take care of the cables, lines and station apparatus, and the precautions used to prevent accidents to men working on the same.

When work is to be done on any apparatus or lines, permission must be obtained from the load dispatcher; this may be done either by telephone or in writing, but in all cases, except emergency, there must be a minimum of twelve hours notice. All such business was formerly conducted in writing, but this rule has been modified because it worked a hardship on the outlying districts. The telephone or written request must contain the name of the foreman who will be in charge, the nature of the work in complete detail, and the length of time that the foreman in charge estimates the job will take. From these conditions the load dispatcher lays out the work and can judge whether or not the operating conditions will permit the rendering of the apparatus or lines unavailable. There may be in the course of the day several requests for jobs and it is part of the load dispatcher's duties to prevent these jobs from conflicting and not to allow enough apparatus to go out of commission to jeopardize the service. In all matters of this kind, the chief load dispatcher's decision is final, and the workmen have no other recourse than to take the decision as given, because of the fact that the load dispatcher's office is controlled directly by the general superintendent, and in all matters of importance the men know that he has been consulted.

After the necessary formalities have been complied with and before the foreman is ready to start work as decided on the load dispatcher has several very important duties and rules to comply with. If the work is on a transmission cable

line, the switchboard operators concerned are instructed to open all oil switches and knife switches which can in any way render the lines alive, and to fill out and place on the control of the oil switch a standard "Red tag," made for this purpose and used for nothing else. These tags are filled out by the various switchboard operators at the load dispatcher's direction and carry a full detailed record of the transaction, one of the tags being placed at each end of the line concerned and another on the load dispatcher's operating board. After these tags are placed in position the operators are instructed to test the lines for potential, and if all tests show the lines to be dead, a ground and short circuit is then ordered on the cable or line terminal. The test for potential consists of inserting a high potential fuse between each conductor and ground, using a suitable insulated wooden rod to protect the man so doing, the fuses being first tested to find out if they are intact. After the operators have ascertained that the feeders are dead, the grounds are put up, using a wooden insulated rod specially designed for this purpose. All grounds and short circuits must be of ample size to carry the predetermined short-circuiting current of the stations concerned, and must be placed in such a manner that they cannot come off unless actually taken off. A standard grounding device is used in the majority of cases.

When this is done, the operators report to the load dispatcher, and when all the reports are in from the various operators, the load dispatcher in turn reports to the foreman in charge of the work to be done, advising him of the cable and lines involved and where the tags, grounds and short-circuits are placed. In all telephone work of this kind, the orders from one man to another are repeated word for word to avoid error; nothing is taken for granted.

FIG. 1—DIAGRAM OF TRANSMISSION SYSTEM OF THE PUBLIC SERVICE ELECTRIC COMPANY

Before starting work, the foreman is instructed to make tests for potential on the lines or cables, and if he is to cut an aerial line he must ground and short-circut the lines on both sides of the cut and work in between the grounds. This is to prevent accidents due to the lines concerned becoming crossed with another live line in a remote territory.

On turning a line back into service, the reverse of the above takes place. A complete record of all these transactions is kept by the switchboard operators and the load dispatcher and the red tags are mailed to the load dispatchers office for reference.

The load dispatchers duties regarding safety also include the sending of ambulances and doctors to injured workmen and the public at large, and control over an automobile pulmotor service.

CONTINUITY OF SERVICE

The system of the Public Service Electric Company has in common with all others a routine method of operating from day to day. In event of any accident to the routine, the load dispatcher assumes complete control of the situation and all operators and station men are subject to his directions. In a system covering so much territory, it is practically impossible to arrange any scheme of automatic signaling devices to notify the load dispatcher of impending trouble. Consequently he is dependent on the switchboard operators for his information. In the event of a short circuit, the operators are trained to communicate with the load dispatcher immediately, and tell him in a clear, quick and concise manner the extent of the trouble and any other information which can be given at the time. From this information the load dispatcher forms his opinions and proceeds to outline a method to clear up the trouble and restore service. This is not as easy a matter as it sounds, for in such a complex system it is almost impossible to get a selective setting on the circuit opening relays, and in consequence there are a great many switches which may open on one short circuit; hence it is a very difficult matter to find out which particular line is in trouble. Training and experience play an important part at this time and make the difference between a long interruption to the service and a short one. The lines and cables are reconnected as fast as possible, the sub-station men starting up their apparatus as soon as current is restored to their stations. In a number of cases there are indicators placed on the sub-station end of the cable which notify the attendant of their condition and reduce the amount of telephoning to a minimum.

It is our practice to have the office of the load dispatcher situated away from the power plants because it is our opinion, that to place him in a position where noise and distraction due to electrical disturbances will affect his judgment, is poor policy.

The number of cases of trouble which the load dispatcher has to handle are of course dependent on the size and capacity of his system. It is part of the load dispatcher's duties to trace these troubles and, if possible, make recommendations for their prevention. The troubles since 1910 are given in Table I. These three classifications for 1913 have been subdivided under the ten heads as given in Table II.

TABLE I—NUMBER OF SHUT-DOWNS

Year	1910	1911	1912	1913
Central station	5	13	12	12
Sub-station	28	21	24	36
Line and cable	81	114	129	155
Total	114	138	165	202

TABLE II—CLASSIFICATION OF TROUBLES DURING 1913.

	25 Cycle		60 Cycle	
	Number	Percent	Number	Percent
Insulator failures	12	22	30	20
Cable failures	2	4	21	14
Central station apparatus	3	5	4	3
Sub-station apparatus	2	4	7	5
Secondary feeder	5	9	23	15
Operating mistakes	2	4	10	7
Storms	9	17	16	11
Outside interferences	9	17	22	15
Mechanical breaks	0	0	0	0
No apparent cause	10	18	15	10

Among apparatus installed to aid the operation of the system and to anticipate electrical troubles is an insulation resistance measuring set which gives on a chart a twenty-four hour record of the resistance to ground of the system. From these charts it is possible for the load dispatcher to anticipate breakdowns of the system and get bad transmission lines out of service before they actually break down.

There is also an arcing ground suppressor which is used to extinguish a single-phase arc to ground on an underground cable, and a localizer which indicates the cable at fault. The records show that 90 percent of the cable failures originate in a single-phase arc to ground, which later develops into a short circuit. The arcing ground suppressor consists of three single-pole oil switches, electrically interlocked to prevent more than one operating at the same time, connected to ground on one side and to a bus-bar on the other. Connected to the suppressor is a differential three-pole relay which remains inactive when the three-phase system is balanced, but when it is unbalanced due to a ground, the relay operates and allows the corresponding phase of the suppressor to ground the same phase of the bus-bar, thus shunting the current and extinguishing the arc.

The localizer comprises a series of pilot lamps connected to relays which are in turn connected to the series transformers on the feeder circuit. A ground causes current to flow through the current transformer and localizer relay, and in consequence the pilot lamp is lighted and the faulty circuit indicated. This seems rather a complicated operation, but is very simple and operates in about a quarter of a second.

After the suppressor and localizer have operated, a good cable is paralleled with the bad one, the faulty cable taken out, then the suppressor and localizer disconnected, all this without any interruption to the service. This apparatus has taken several years to develop and there are some minor changes yet to be made, but out of a record of over two hundred operations it has taken care of 95 percent perfectly. A fifteen-minute delay to the entire system was caused by a cable end bell short-circuiting on an armature lead on a generator at Marion before the suppressor was installed. The same thing happened a few weeks ago and the suppressor took care of it perfectly, so that no one outside of Marion was the wiser. Instances are on record where chains have been accidently dropped on station bus-bars and no interruption occurred. Some years ago this would have played havoc with the bus-bars and the service.

ECONOMICAL SERVICE

Naturally, in a system whose growth extends over a period of years, there is a large variation in the kind of apparatus installed. It is the load dispatcher's duty to see that the apparatus is operated according to the rate of steam consumption of the separate stations and that the current is manufactured with the most up-to-date apparatus. In plain view of his desk is a frame containing load curves and station water rates over a period of five years; load curves are drawn up daily from each station and sub-station, and from these the dispatcher handles his loads. The station which is the most economical is driven at its best point and the others are operated on orders from the dispatcher to maintain this point.

SUMMARY

A dispatcher's duties are very confining and trying to the nerves, and the men for this position must be physically fitted for it. Frequent days off for rest and recreation must be provided; at the same time they must be allowed to make frequent visits to the various stations and sub-stations of both their own and other companies, and to cover the transmission system so as to get the geographical layout of the cables and lines and to have the system at their fingers' ends at all times.

A good load dispatcher has to combine in a general way the knowledge of practically every department so as to be able to discuss all subjects intelligently, and above all, he must be a man of diplomacy and cool judgment. It is needless to say that such men are rare.

THE SYSTEM OPERATING DEPARTMENT OF THE DUQUESNE LIGHT COMPANY

E. C. Stone,
System Operator

When the service of a central station company's customer is interrupted, even if for only a few minutes, the customer is very likely to feel that the interruption is unnecessary or unduly long, and that the central station company is not giving the attention to its service that it should. That this is not the case, but that on the contrary the central stations fully realize the seriousness of an outage and are doing everything possible to reduce interruptions to a minimum, could not be better proven than by the development of load dispatching and system operating departments in the larger companies during recent years. The sole duty of these departments is to see that satisfactory service is delivered, that all avoidable outages are eliminated, and that unavoidable interruptions, such as those due to lightning, wind and snow are reduced to a minimum. In the Duquesne Light Company of Pittsburgh, Pa., for example, it is the business of the system operator, broadly speaking, to see that sufficient power is available on all parts of the system, at all times, to supply adequately the requirements of the company's 42 000 customers, who are spread over an area of more than 250 square miles. That this centralized control is advantageous is very vividly demonstrated by the fact that, since the office of system operator has been established, the average length of interruption to service on the main high tension system has been reduced approximately 75 percent.

The system of the Duquesne Light Company, exclusive of direct-current stations for the supply of power for street railways, consists of four main power plants ranging in capacity from 3 800 to 45 000 kw, and 175 miles of 11 000 volt high-tension transmission lines, to which are connected approximately 50 sub-stations. The entire system is operated in parallel.

The general plan of operation of the high-tension system is worked out with a view of obtaining the greatest economy of operation under normal conditions, together with the least disturbance and most rapid re-establishment of service in times of trouble. Each of the smaller plants is connected with the main plant by one or two direct tie lines, but none of the smaller plants are tied in with each other except through the bus-bars of the main plant. These tie lines pass through several sub-stations, at each of which is an automatic circuit breaker, with a definite time limit relay, for sectionalizing each tie line. Two plants operated in parallel will ordinarily break apart if a severe disturbance comes in on the bus of either, just as a synchronous motor will drop out of step with a sudden drop in voltage. It is very essential that the plants in parallel should break apart in such a way that each will hold on to approximately the load it was previously carrying, for if one of them, especially the smaller one, gets a big increase in load, its frequency will go down, and make synchronizing impossible, so that the only relief for the situation is an interruption to that part of the service creating the excessive load, while transferring it to the other plant. To avoid these unnecessary interruptions, definite

time limit relays are made use of. By the proper adjustment of these relays, the separation of the two plants is forced at such a point as will leave each with approximately its own load. Since the main plant is much larger than any of the others, it is our general practice to arrange for each of the smaller plants to drop some load to the large plant in case of separation, and care is always taken to see that the main plant has sufficient spare capacity to take up the load that may be dropped by the smaller stations. For instance, normally the circuit breakers on the lines between plants *1* and *4* are set as shown in Fig. 1. In case of trouble on the bus of either of these plants, the instantaneous circuit breakers at sub-station *C* will open, leaving the load of that station on plant *4*, which under normal conditions would make the total load on that plant slightly less than was carried before the separation. If, however, it becomes necessary to take down some of the generators in plant *4* for repairs, so that its capacity is reduced, then one or both of the non-automatic switches in sub-station *C* would be changd to automatic instantaneous overload trip and the corresponding instantaneous circuit breakers would be made non-automatic, so that either half or the whole load of sub-station *C* would be left on plant *1* when a separation occurred, thus keeping down the load on plant *4* to what it could carry independently of plant *1*. It should be noted here that it is the practice to make all

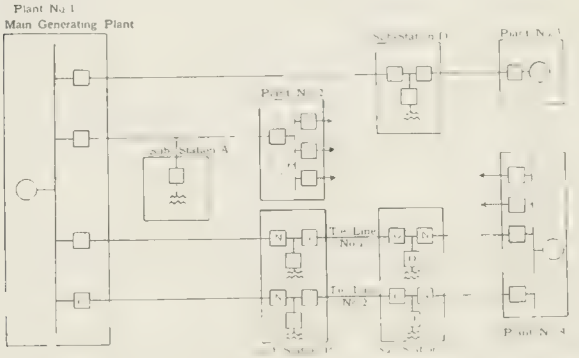

FIG. 1—GENERAL SCHEME OF PARALLEL OPERATION WITH TIME-LIMIT RELAYS

The generators are represented by circles. The time setting, in seconds, is indicated by the figures set inside the squares, which represent the circuit breakers. *N* indicates a non-automatic switch. *O* indicates that the time relay is cut out, so that the circuit breaker opens instantaneously on short circuit.

switches on the incoming feeders to sub-stations non-automatic. This is to avoid an unnecessarily long time element on the circuit breaker at the power plant on lines where several sub-stations are in series.

In general all lines are operated independently of each other, being connected only through the power-house busses. This is in order that a short-circuit or other disturbance will not interrupt any service except that fed from the line on which the trouble occurs. Each sub-station, except a few small stations in outlying districts where the service would not warrant the increased expense, is provided with two independent feeders. The station load is carried on one of them, while the other is kept "hot" at all times, so that if the feeder in use is disconnected, the service can immediately be re-established on the second line.

Printed bulletins covering instructions for regular operation, as well as for the re-establishment of service in times of trouble, are gotten out for each power plant and sub-station. In this way, each operator is able to keep his service going as long as he has a hot line—which is practically continuously—without waiting for instructions from the system operator, while at the same time the system operator knows what each station is doing. These instructions cover a rule whereby every station must be clear of a line in one minute after it goes off, so that any line available can be safely connected to a station, after being out a minute, without delaying to call that station first. Furthermore, the power plants have definite instructions for putting on lines after an interruption, so as to secure re-establishment of service in the quickest possible time. Ordinarily, therefore, service at the various stations can be re-established independently of the telephone, a very important point, since considerable delay must necessarily be involved in getting a connection and carrying on conversation, while in severe storms the telephone service is likely to be very unsatisfactory. It therefore remains for the system operator in times of trouble, only to take care of special situations, get the plants synchronized, readjust the loads so that no lines will be overloaded, supervise testing of defective lines and apparatus and location of trouble, and see that work on repairs is promptly started. To make the printed instructions effective, the station operators are required at stated intervals to go through the steps necessary to re-establish service after an interruption. This not only keeps the operators in training but keeps all switches, etc., in good working order or discloses any defects in time to prevent their causing serious trouble. These switching practices are always carried out at periods of light load, when an interruption, if produced, would cause little inconvenience.

Another important function of the system operator is the supervision of taking off lines or apparatus for repairs, or putting new apparatus in service. It is customary for a line foreman who wants to work on a high-tension line to get in touch with the system operator the day previous and advise him what lines are wanted and for how long. The system operator will then determine whether the foreman's requests conflict with other plans. If there are no conflicts, and the line can be disconnected without inconvenience to the service, the foreman is notified that he can have the line as requested. Otherwise arrangements will be made for a different time. No lines are permitted off in storms or at periods of peak loads.

When new apparatus is put in service notwithstanding the fact that it is always tested at over-potential it is nevertheless first connected to the station bus at a time when an interruption if caused would be least serious—for experience has shown that under new conditions not all possibilities can be foreseen, and some interruptions are liable to be caused when new apparatus is first installed.

The equipment used by the system operator in doing his work is extremely simple, but so far has proved very efficient. Private lines directly from the power switchboards of all important stations come into the system operator's desk through a special telephone switchboard, which was designed by Mr. M. W. Cooke, especially for this service. This board is arranged to be operated from both sides of the desk, and is equipped with supervising lights so that two men can work at once, on either side of the desk, and each will know at all times what the other is doing. There are four jacks on each side so that eight parties can be communicated with simultaneously if desired. Arrangement is also made so that any two incoming lines can be connected together for conversation between outside parties without tying up either of the system operator's telephones. The private lines give the system operator instant communication with the operators at the stations.

At the side of the desk are located a frequency meter and recording voltmeter. Since the whole system is in parallel, these instruments indicate at all times the condition of the system, and either steam or electrical trouble is detected instantly by their indications. On the wall near the desk is a large bulletin board on which are placed permanent and temporary orders regarding the operation of the system. When a man comes to work, it is his first duty to read and initial all new notices on the bulletin board. There are also

posted here the regulations regarding taking high-tension lines off for repairs, a list of physicians employed by the company, a list of parties to be called under various conditions of trouble, and a telephone directory of all customers connected directly to the high-tension lines.

A daily log is kept of all switching and other events that occur, entries being made immediately on their occurrence, so that this log is an up-to-the-minute record of the condition of the system at all times. When an entry for a line off or other irregular operating condition is made, a column in the right hand margin of the log sheet is left blank. This column is not filled in until the line is back on and everything covered by that entry is in regular operating order, so that a glance up this column on the margin of the sheet indicates at once what points are in need of special attention. At the bottom of the sheet is a space for the date and the initials, with time of coming on and off of each man. In addition to this, a load report is kept. This gives a complete record of the kilowatts, voltage, power-factor, condition of steam and capacity in service at all 11 000 volt power stations and the amount of energy passing through circuit breakers which would open if parallel plants were disconnected. This data is obtained by phone from the plants every hour throughout the day, and every half hour during the peak period. The keeping of this report not only furnishes very important information, but keeps the system operator in close touch with the operators at the plants and develops that personal interest which is such an important factor in securing co-operation between the different men.

LOAD DISPATCHING SYSTEM OF THE PITTSBURGH RAILWAYS COMPANY

J. W. Welsh
Electrical Engineer and Traffic Agent

The load dispatching system of the Pittsburgh Railways Company was inaugurated in 1907 by Mr. P. N. Jones, general manager. At that time the system was supplied principally from eight direct-current power stations. Sub-stations were just beginning to be installed to take care of the increase in load. The various stations were operated almost independently, parallel operation being employed only to a very limited extent, and the load dispatcher's duties being largely of a diplomatic nature in amalgamating the conflicting interests of the chief engineers of the various power stations. With the extension of the principle of parallel operation between stations opportunity arose for a difference of opinion between station engineers as to the proper share of the system load to be carried by each. This was particularly true when unusual loads occurred, as each engineer felt his station was made to carry the brunt of the overload. There was, equally, an opportunity for complaint when there was not enough load to go around. As soon as the station engineers realized the advantage of coöperation through the load dispatcher these difficulties disappeared.

The network comprising the direct-current feeder and trolley system of the Pittsburgh Railways Company now includes about 1 300 miles of wire, to which power is supplied from seven direct-current generating stations and sixteen sub-stations, containing a total of 75 generating and converting units. The equipment of the city sub-stations consists of motor-generator sets, which permit the adjustment of load between stations by variation of voltage, as all stations are connected in parallel by tie lines or feeders.

The various sections of trolley on the system are fed from direct-current generating plants or sub-stations by numerous feeders, each one of which is independent and sectionalized by automatic circuit breakers, so that trouble on a section may be located and isolated. Each feeder section supplies on the average 6.5 miles of track. To reduce the voltage drop and increase the reliability of service on a section, a feeder is, where possible, connected to two or more stations; this feeder then acts as a tie line, and reduces the fluctuation of load at each station. Where it is possible to reach several feeders at a point distant from a station, the sections are tied together at an equalizing board, which consists of a bus to which each feeder is connected by an automatic circuit breaker. In addition, some feeders are connected together through knife switches, mounted on poles, operated by emergency men. The use of such devices for interconnecting feeders reduces the transmission losses by working all of the copper all of the time, taking advantage of the diversity factor of the fluctuating load on the feeders. A diagram of the direct-current feeder system, showing stations, equalizing boards, and pole switches, has been painted on the wall of the load dispatcher's office, so that he can see at a glance the effect of operating any switch.

The chief business of the load dispatcher is to maintain a sufficient supply of power on the trolley wire at all times and under all circumstances; to restore power service as soon as possible after interruptions; and under normal conditions, to direct the operation of the stations to obtain the maximum economy. The change in load for each hour of the day, as shown in Fig. 1, follows the variation in traffic through the morning peak, mid-day, evening rush-hour, and night periods. The cutting in and out of machines to meet this curve is under the direct supervision of the load dispatcher. The uniformity of this curve, however, is frequently disturbed by unusual conditions. The weather, for example, has a marked influence on the load. A heavy rain cleans the track and reduces the load; a light rain or snow mixing with the dust makes a greasy rail, causing slipping of the wheels and an increase in the load; the worst condition is a heavy dry snow, on which the wheels are constantly climbing and slipping. Besides this, the use of electric heaters makes a great increase in the load in cold weather. It will be seen therefore that the weather is one of the chief concerns of the load dispatcher, as he must be able to anticipate the amount of the peak.

As a result of the parallel operation of stations and the use of motor generator sets, the load dispatcher is able to shift the load between stations in accordance with the available capacity and conditions at each place, both by varying station voltages, and by opening or closing tie line feeder switches at stations, equalizing boards, and on poles. Some of the stations are equipped with double direct-current bus systems, which permit carrying different voltages on different feeders, under direction of the load dispatcher; thus the voltage on an overloaded section may be raised 50 or 100 volts, or one station may give another a great deal of help by raising the voltage over a tie line, while not changing the main bus voltage. All motor-generator sets are specified for operation over a range of 500 to 600 volts at full capacity, and higher or lower voltages may be carried in emergencies. With a system on which the peaks approximate very closely the station capacities, the distribution of the load in accordance with the available capacity often presents some interesting problems to the load dispatcher, particularly when the loss of a machine or high-tension line cripples a station. During the morning and evening peaks, readings of the load at the principal power and sub-stations are taken by the load dispatcher on a sheet, as shown in Fig. 2, and orders are given to the operators to raise or lower voltage, to keep the load properly distributed, and to relieve overload on any station. Notes regarding switching, and all occurrences affecting power are made on this sheet as well as a record of the temperature and condition of the weather.

On the wall in the load dispatcher's office is also a diagram showing the 11 000 volt, 60 cycle high-tension system supplying the city sub-stations. The high-tension bus arrangement at a station is designed to allow considerable flexibility in the distribution of load between the lines and cables, to

permit the most efficient use of the available line capacity and to provide adequate emergency service for conditions caused by accidents to lines and repairs to the same. At nearly all stations the load of one line may be transferred to another. The load dispatcher directs the necessary switching of 11 000 volt lines at stub-stations, in conjuction with the system operator of the power company.

The interurban high-tension system of the company includes 72 miles of 22 000 volt line and six railway sub-stations; there are also several coal mine power customers supplied from these high-tension lines. The main system is in the form of a *Y*. The trunk feeder may be supplied from either of two power stations, and an auxiliary line tapping the middle of one leg of the *Y* connects to a third power station. All three legs of the *Y* are sub-divided by automatic time-limit oil circuit breakers at the various stations; the junction of the *Y* is a double-bus switching station which permits numerous combinations of circuits to insure continuity of service. The relays of the various circuit breakers have graduated time settings to secure selective action, all having inverse

PITTSBURGH RAILWAYS COMPANY
DAILY LOAD DISPATCHER'S REPORT

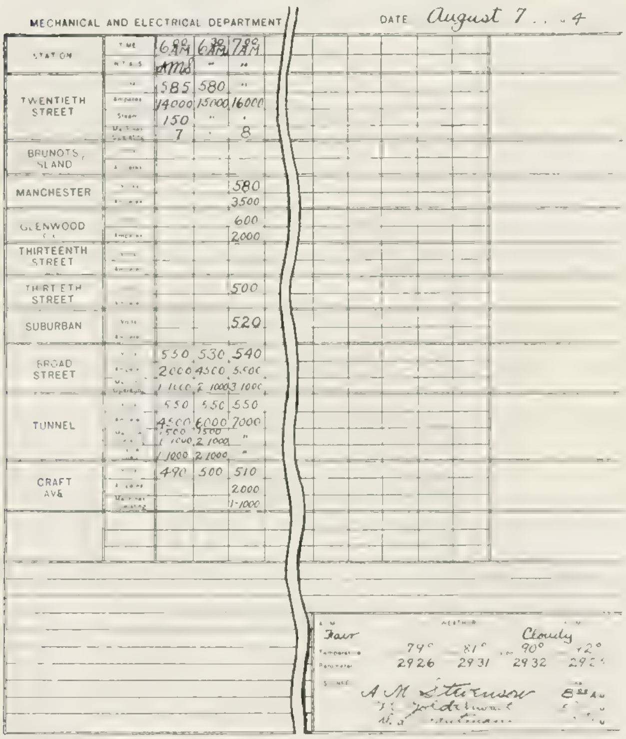

FIG. 1—LOAD DISPATCHER'S DAILY REPORT

time elements except at the main transformer station, where definite time element relays are used. The number of sub-stations and power customers on the line makes these elaborate switching arrangements necessary to localize disturbances and prevent trouble on a section interrupting the whole system. All switching on this system is done by telephone orders from the load dispatcher.

Before any sub-station equipment, or high-tension lines can be taken out of service for repairs, arrangements must first be made with the load dispatcher in order that there will be assurance that capacity will be available to supply the deficiency. The clearing of a high-tension line is always handled from the load dispatcher's office, but before a man is allowed to work on it, he must report personally to the sub-station operators at each end of the line; the operators will under no circumstances put the power on again until the same man has reported himself clear of the line. The procedure is made a matter of record on the form shown in Fig. 3. This method eliminates the possibility of accidents due to the mistake of a third party, and the workman is responsible for his own protection.

Time is the important element in emergencies, and it takes time to give orders by telephone, particularly when trouble affects several stations at once. To obviate delay as much as possible, emergency instructions are posted in each station to direct the procedure in time of trouble, as far as

PITTSBURGH RAILWAYS CO.

ELECTRICAL AND MECHANICAL DEPT.

REPORT OF HIGH TENSION OUTAGE

Washington Junction SUB STATION

Tunnel Jct #1 Line Off 7 10 A M. 7/7/14 (Time) (Date)

Cause Working on line

MEN REPORTED ON LINE

By John Joyce at 7 10 A M. 7/7/14

By Jim O'Brien at 7 20 A M. 7/7/14

By at M.

MEN REPORTED OFF LINE

By John Joyce at 11 10 A M. 7/7/14

By Jim O'Brien at 11 20 A M. 7/7/14

By at M.

Line in service at 11 10 A M. by order of Load Dispatcher

Remarks: Junction Bus hot from Rankin

J. J. Burrell Station Operator

WARNING:—This report refers to but ONE High Tension line. Men must be reported clear by same person who reported them on line.

If men are reported on line by more than one person, fill out line for each person and be sure all have reported clear before going in on line.

When report is completed send to Load Dispatcher, Room 516, 435 6th Ave.

FIG. 2—REPORT TO LOAD DISPATCHER OF HIGH TENSION OUTAGE

the trouble can be anticipated. Operators call the load dispatcher only after proceeding as far as possible under the given rules and in many cases this has enabled the service to be restored at once.

The load dispatcher's office contains a telephone switchboard communicating with the principal power houses and sub-stations, and through the private branch exchange to all other company 'phones. An intercommunicating telephone system also connects with the other offices of the company in the building. An indicating voltmeter, indicating frequency meter, and graphic volt and frequency meters indicate and record all changes and disturbances on the alternating-curren system supplying the sub-stations. The alternating-current voltmeter is particularly valuable for giving instant notice of any trouble on the high-tension lines. A barometer and thermometer are used for weather observations.

Besides the work in connection with the power supply, the office is used by all departments of the company as a clearing house for general information and the delivery of telephone messages from superintendents to dispatcher and foremen, particularly at night. As the men work in several

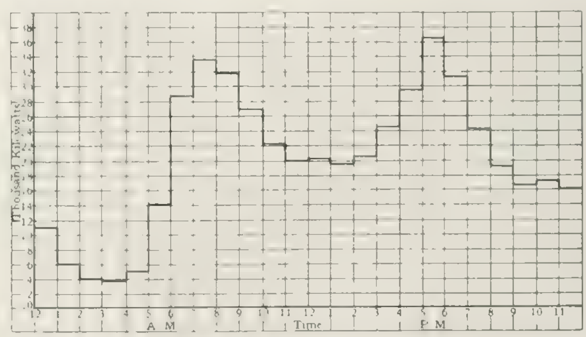

FIG. 3—TYPICAL DAILY LOAD OF THE PITTSBURGH RAILWAYS COMPANY

shifts, there is a load dispatcher on duty each hour of the day and night. This service is greatly appreciated by officials of the company as it frequently obviates the necessity of calling a man out of bed, when the load dispatcher can handle the situation without advice.

THE ELECTRIC JOURNAL

VOL. XI NOVEMBER, 1914 No. 11

Methods of Alternator Excitation

The article in this issue, entitled "Excitation and Voltage Control" by Mr. J. A. Johnson, which describes in detail the system of excitation employed by The Ontario Power Company, is one of the most comprehensive and well written discussions which it has been our pleasure to review for a long time. One striking thing dwelt upon is the inadequacy of the original central supply system of excitation, the detail of the reasons for this inadequacy and the measures taken in answer. In our opinion, this recognition of the inadequacy of the central supply system for excitation is generic rather than specific for this one case. The tendency away from the central supply system is general and many of the reasons for it are the same as those given for The Ontario Power Company's change. It is one of the developments due to the extremely rapid growth of central station supply systems in recent years.

Although the method of driving the individual exciters described by Mr. Johnson is, without question, the best solution for his particular case, it is doubtful whether it is the best for the general case. While it is generally agreed that an individual exciter for each large generating unit is the logical method of exciting the modern generating station, we believe further that each individual exciter should be direct connected to the shaft of the generator, rather than driven by the somewhat complicated method described by Mr. Johnson. This method, of course, has some advantages, but we do not believe that its advantages are sufficient to outweigh the complications which the exigencies of the case compelled in their plant. While it is true that the direct-connected exciter may suffer from possible speed changes of the main unit, we believe that the modern voltage regulator is more than able to take care of the fluctuations which might otherwise occur.

As to the question of cost, it is admitted that the cost of the exciters themselves will be greater when attached direct to the generators than when massed into a central system. However, when we consider the prime movers necessary for the central system method of excitation, the long exciter leads that are necessary (not necessary with individual exciters) the more complicated switchboard, etc., the balance with respect to cost, as well as reliability and convenience, often rests with the individual drive. The emphasis upon this particular feature is probably the chief lesson which we can draw from Mr. Johnson's timely discussion of his case. P. M. LINCOLN

Improved Sub-Station Protective Devices

One of the modern tendencies is towards an increasing number of isolated sub-stations, and the problem of providing proper protective devices has been one of the greatest importance. Devices which are positive in action and reliable in setting are necessary in order to eliminate interruptions to service, to reduce the operating cost and to provide for the safety of the operators. It is a gratifying fact that the three modern problems, "Continuity of Service," "Decreased Costs," and "Safety First" are usually solved by the same developments in electrical design.

Mr. B. H. Smith, in this issue of the JOURNAL, shows how a recent engineering development makes possible the use of a circuit-closing relay for tripping circuit breakers directly from series-transformers. Most isolated sub-stations do not have direct current. Many cannot have low voltage alternating current, except at considerable expense. Shunt tripping from alternating current or from direct current converted from the sub-station alternating current (without the use of storage batteries) is unsatisfactory owing to the fact that, under many short-circuit conditions, the voltage of the alternating-current line drops and a shunt tripping device which is dependent on the same circuit is not operative when it is most needed. Series tripping through relays has been possible in the past only by the use of solenoid relays with leather bellows time element device. Such relays have not been entirely satisfactory as a leather bellows with needle valve adjustment will not retain its accuracy in time setting.

Relays built on the induction principle are more satisfactory for overload tripping, as pointed out by Mr. F. E. Ricketts, in the JOURNAL for April, 1914. Heretofore such relays have been expensive and, being necessarily of the circuit closing type, have not been adapted for series tripping. An induction relay has now been made available at a moderate price to replace the solenoid and bellows type relay. It is of special importance, therefore, that the application of the circuit-closing induction-type relay to series transformer tripping of circuit breakers has been found possible.

When it is considered that motor-generator sets and storage batteries have in the past been installed at considerable expense to do the same work that this device will do at a negligible first cost and at no cost for maintenance, the importance of this invention can readily be seen. T. A. MCDOWELL

The Neutralizing Transformer

The article on the neutralizing transformer in this issue of the JOURNAL prompts me to give some further account of its early development. A number of years ago it was apprehended that interference might be caused in telephone circuits by the operation of single-phase railways. An arrangement was made by which the Westinghouse Electric & Mfg. Company would provide facilities for tests to be made by the American Telephone & Telegraph Company, and the engineering departments of the two Companies would coöperate in the investigation. After a number of tests it was determined that there would, in certain cases, be considerable interference unless some means were taken to prevent it. The suggestions which were made did not seem feasible or applicable to all cases.

Everything seemed to be negative. I recalled the statement that "when you have an alternating current, you have something that you can do something with," and set about to do something. The fundamental fact of electro-magnetic induction between the railway circuit as a primary and the telephone circuit as a secondary was very simple. Sketches were drawn with series transformers between trolley and telephone circuits for introducing into the latter an electro-motive force which would oppose or neutralize that which was produced in it by induction from the railway circuit due to the parallelism of the circuits. Obviously the e.m.f. on the transformer could not at all times be equal and opposite to that induced in the other circuit for various reasons. For example, a train might move from one transformer to the next without affecting the current through the transformer, although the changing position of the train would modify the length of exposure of the telephone line to induction.

Furthermore, current in the trolley may be regarded as composed of two parts, one of which returns by the track and the other by the earth. The former has relatively small effect in causing induction in adjacent circuits, as the outgoing and return primary currents are only about twenty feet apart. On the other hand, the current which returns by the earth is a considerable distance from the outgoing current and would, therefore, induce a relatively high e.m.f. in the telephone circuit, i. e., in a circuit composed of overhead wires and the earth as a return. Hence the e.m.f. is nearly proportional to the earth current. It was therefore suggested that a transformer with a differential winding be used which would have one primary coil inserted in the trolley circuit and a second one inserted in the track circuit, so that the resultant e.m.f. would be proportional to the earth circuit. It was further proposed to place the transformers at frequent intervals, so that the change in condition when a car passed a transformer would not be too great. This scheme did not appeal to the telephone engineers, but they were ready to try whatever was presented. I was not very sanguine of success, but felt that it was a step in the right direction, and we might learn something by trying it.

As an assistant in this work I secured Mr. Arthur J. Sweet. He said that he was not very familiar with alternating-current devices. He had studied alternating currents in college, but had had no practical experience and he explained that his idea while taking his college course was to specialize in philosophy. However, I outlined the plan of using transformers, and asked him to take the matter up with some of the transformer designers and get the transformers made. In a day or two he reported that he did not think the scheme was a good one; he pointed out the difficulties and had a plan for overcoming them. He stated that what was needed was an e.m.f. equal at all times to that induced in the telephone circuit, which could be introduced into the telephone circuit by the secondary of a transformer. In order to produce such e.m.f. in the transformer it would be necessary to have a primary circuit in which the e.m.f. was the same as that on the telephone circuit. The way to get such a primary e.m.f. was to place the primary wire close to the telephone circuit, so that it would be subject to the same inductive influences as the telephone circuit. The plan seemed to meet the conditions so admirably that the objection to proposing an additional primary circuit running parallel with the telephone wires was overcome, and measures were taken to try out the plan on experimental circuits. It is interesting to note that the ability in analyzing problems developed in the study of philosophy came into good service in problems of electro-magnetic induction.

In ordinary transpositions, the wires of a circuit are transposed so that the e.m.f. induced in a section of one mile, for example, will be neutralized by the induction of the next mile, because the transpositions of the wires cause the two e.m.f.s to oppose one another. In the case of the induction in a secondary circuit consisting of telephone or telegraph wire with earth return, it is obviously impossible to make the transpositions. What is done by the neutralizing transformer is to take two circuits extending through the same mile and introduce the e.m.f. of one of these circuits into the other by means of the transformer, the connections being such that the two e.m.f.s are in opposite directions. The neutralizing transformer is really a special case of the transposition of circuits.

The neutralizing transformer scheme was tested by the engineers of the Western Union Telegraph Company and introduced on the lines along the New Haven Railroad. The conditions were predetermined; the transformers were designed and erected before the current had been placed upon the railway circuit, and have continued in service without change until the recent rearrangement of the railway circuits by which the induction in adjacent wires was practically eliminated. It may be noted that the conditions formerly existing on the New Haven System were exceptionally severe, as the heavy service of the four-track system

was supplied from a station near one end. Very heavy currents were, therefore, carried for considerable distances and the induced e.m.f. did not have the benefit of the counter-effect which is produced when the railway current comes from opposite directions from supply stations at both ends of the line.

It was hoped that the transformer might be of assistance in reducing the high frequency induction, as well as that due to the fundamental frequency. The high frequency, due to commutation and the like, is the noise producing factor in the telephone. It was found that the first neutralizing transformers, which were designed for telegraph circuits and did not provide for close electrostatic and magnetic balance, tended to increase rather than diminish the noise in telephone circuits. The first conclusion was that the transformer was inapplicable to telephonic service, but it seemed worth while to correct the known faults and try again. Proper design and construction produced a transformer which was found to have little or no effect upon the noise. In one of the early tests, in which neutralization as measured by a voltmeter was very nearly perfect, there was scarcely a perceptible effect on the noise whether the transformer was connected so that the e.m.f. at fundamental frequency was neutralized, whether the connection was in the opposite direction so that the e.m.f. in the circuit was doubled, or whether the transformer was cut out entirely. The result, therefore, seemed to be a failure, and the considerable effort which had been devoted to the construction of the transformer seemed to be lost. The transformer was then deemed suitable for telegraph circuits, but useless for telephone purposes. Some time later, however, it was found desirable to introduce the transformers into circuits which served for both telegraph and telephone service. The transformer tests had already indicated that a properly designed transformer was suitable for neutralizing the fundamental frequency and that it could be neutralized without introducing a noise. Transformers of this kind are described in the article by Mr. Shaw as having performed a useful service in commercial circuits. CHAS. F. SCOTT

The Protection of Telephone Equipment

While the fundamental conditions involved in the protection of telephone equipment against damage from excessive potentials or currents are essentially those involved in the protection of any electrical equipment which may be subject to the strains of potentials and currents in excess of those which it is designed to withstand, the practical fulfillment of those conditions in the telephone plant is complicated by factors not ordinarily encountered with other electrical equipment.

From its very nature, telephone apparatus, both in the central office and in the substation, is necessarily of relatively low dielectric strength and small current carrying capacity. These factors alone, by lowering the upper limit of permissible voltage and current, greatly extend the range of conditions requiring protection. They also very greatly increase the numerical hazards of exposure by throwing into the dangerous class most of the circuits commonly employed for the distribution of power, lighting and street railway propulsion currents.

To those inherent weakness factors must be added the difficulties which arise on account of the great multiplicity of circuits concentrated in the central offices and spreading out over the country in a huge network. These circuits have innumerable points where contact with power and lighting circuits is possible, and almost unlimited opportunity, through exposure in the network itself, for carrying dangerous potentials and currents to all parts of the plant if the protective equipment is defective. It is also easy to see that this huge network, which contains a large amount of aerial wire, is an inviting field for disturbance from lightning.

Further, in the central offices and at cable boxes the number of circuits to be cared for makes it imperative that the size of the protectors be reduced to the smallest possible dimensions. At substations the dimensional requirements, while not usually affected by the number of circuits, are nevertheless circumscribed, owing to the fact that the protective apparatus must be as small and inconspicuous as possible, consistent with proper operation, in order to be reasonably unobjectionable to the person in whose house it is placed. Although the cost of protector maintenance is always a serious matter for the designer of telephone protective apparatus, it becomes a paramount question because so large a part of telephone protectors are installed at points remote from the central offices and entirely away from the possibilities of even casual inspection, except at infrequent intervals. The cost of clearing telephone protector troubles at outlying substations is in many cases extremely high, so that everything possible, consistent with the effective functioning of the device, must be done to reduce the number of visits from the maintenance force.

Above everything else, however, is the fact that the apparatus must operate to protect efficiently the lives and property of those on whose premises it is installed. This means that the protectors must not only be efficient in preventing potentials which might be dangerous to life from reaching the telephone instruments used by the subscribers, but also currents which, through overheating of the instrument parts, might constitute a fire hazard. Also, since it is frequently impossible to mount telephone protective apparatus in fireproof locations, the operation of the protector must not in itself constitute a fire hazard.

In the article on "Protection of Telephone Circuits" Mr. Darrah points out in detail some of the numerous problems which cover the field of telephone protection and some of the methods and apparatus which have successfully solved these problems and been efficient in protecting the lives of telephone subscribers and employees and the property of the public and the telephone companies. F. B. JEWETT

Excitation and Voltage Control

IN THE PLANT OF THE ONTARIO POWER COMPANY OF NIAGARA FALLS

J. A. Johnson
Electrical Engineer,
The Ontario Power Company

THE ONTARIO POWER COMPANY has recently developed and put into successful operation a new system of excitation and voltage control, the fundamental feature of which is the use of a separate individual exciter and automatic voltage regulator for each of its main generators, instead of the usual system of a single central direct-current plant common to the entire installation. By reason of the rather more than usual importance of this innovation, due to its having subsequently been adopted, in whole or in part, for several other large plants, including those of the Mississippi River Power Company at Keokuk, The Shawinigan Water and Power Company at Shawinigan Falls, Quebec and others, it has been thought that a description of the pioneer installation would be of interest and value.

THE GENERAL features of the plant of the Ontario Power Company are now too well known to need further description. Suffice it to say that in its present state of completion it contains fourteen units ranging in capacity from 10 000 to 13 000 horse-power each, and has a total output of upwards of 150 000 horse-power. When the development was planned, its designers had no knowledge as to how its ultimate output would be utilized or what portion of it would require transformation to long distance transmission voltage; and at that time power stations had not reached capacities where the necessity for sub-division on account of excessive short-circuit currents had become manifest. The ultimate development was then conceived as a single great reservoir of power, at constant voltage, to be drawn upon as required. For these reasons no system of excitation was seriously considered other than the conventional central direct-current system. The original six-unit plant was, therefore, laid out with duplicate turbine-driven exciter units. At a somewhat later date these units were equipped with Tirrill regulators for automatic voltage control.

As the capacity of the plant increased by the addition of generators, it began to be apparent that division of the load into groups would be desirable, and possibly necessary, due to the excessive short-circuit currents developed with all machines in parallel. At first the load divided itself naturally into two groups, one supplied at high voltage for long distance transmission, the other with generator voltage (12 000 volts) for local consumption. Later, a third natural group appeared requiring low voltage power transmitted by underground cables. These sub-divisions just about kept pace with the general increase in the load so that no one group became of excessive size. But with the appearance of the third group the limit of capacity of the exciter system was practically reached and a limit of flexibility appeared in that at least one of the two exciters had to be used in common by two of the load groups, thus causing disturbance of both loads by the automatic regulators, when either one was in trouble.

A central exciter plant for the entire ultimate development had been contemplated from the start, but up to this time little consideration had been given to any other plan than that involving large direct-current generators, in other words, practically a duplication of the original exciter plant on a larger scale. Now the necessity for automatic regulation, of sub-division into independent groups, and the uncertainty as to the size and number of groups required, gave rise to question as to whether some more flexible system was not desirable and possible.

In the general design of the plant one of the fundamental principles adopted was that each generating unit should be considered as a separate and complete plant, capable of independent operation, although normally to be operated all in multiple. This conception was carried out so far as the alternating-current end was concerned, the circuits being so arranged that the output of each unit might pass through the station independently, but the idea had not been extended to the exciter system. Such an individualized system would, of course, possess the maximum possible flexibility and was, therefore, taken as the ideal to be approached as nearly as might be possible.

While such a completely individualized system would be entirely feasible with a hand-regulated plant, it presented at least one difficulty not previously encountered in the art of power generation if individual automatic regulation was adopted. This difficulty was the instability of power-factor or wattless current division between generators operating in parallel with independent individual voltage regulation. This instability exists because it is entirely consistent with the condition of equal terminal voltages on all machines, and the voltage is the only thing which is under control. Such an unstable condition is, of course, entirely incompatible with successful operation. In the fall of 1909, while the plant was still being operated in two independently regulated groups, an attempt was made to operate these two groups in multiple, with exactly the result above described. At this time a method of overcoming this difficulty was originated jointly by Mr. E. D. King, then assistant superintendent, Mr. H. S. Baker and the writer, which made possible the system of individual excitation subse-

quently adopted. This device will be described as it is a fundamental element of the new system.

Having thus removed the only obstacle in the way of individual excitation and regulation, the question resolved itself into a choice among the many possible methods of accomplishing it. The following plans were given consideration:—

1—Exciter on the generator shaft.
2—Exciter driven by a belt, chain or gear from the main generator shaft.
3—Exciter driven by a separate turbine fed from the main busses.
4—Exciter driven by a motor fed directly from the main generator.
5—Exciters for several units on the same shaft driven by a separate turbine.
6—Exciters driven by motors with power from the main busses.
7—Exciters driven by motors with power from a separate source.

Of these plans *1*, *2*, *4* and *6* all possess a decided disadvantage in that the exciters are subject to the same speed variation as the main units. This is, perhaps, not serious when on regulator control, but becomes so when such control may be temporarily interrupted, especially in the event of a runaway.

Plan *1* is only with difficulty adapted to an existing plant not originally so designed and was also unsuitable in this case on account of the low speed of the generators (187.5 r.p.m.).

Plan *2* was practically prohibited by the required capacity of the exciters in combination with the low generator speed.

Plan *3* is a very simple and desirable method in some respects but difficult to apply to an existing plant.

Plan *4* might be used in the case of low voltage generators but could only with great difficulty and by sacrificing simplicity be adapted to high voltage generators. Furthermore, a separate source would be required for starting.

Plan *5* is possible but somewhat fantastic and possesses in common with the central direct-current system the disadvantage that the exciting power must be distributed at low voltage.

Plan *6* is a simple method but subject to the disadvantage of speed variation, as above noted. It is also somewhat indirect, and to that extent unreliable, and is not completely self-starting. It is, of all the methods proposed, the one usually most adaptable to an existing plant.

Plan *7* possesses all the advantages of plan *6* and lacks its draw-backs, being self-starting and independent of the speed of the main units. It was finally decided to adopt plan *7* with the circuits so arranged that plan *6* could be reverted to as a relay in case of necessity.

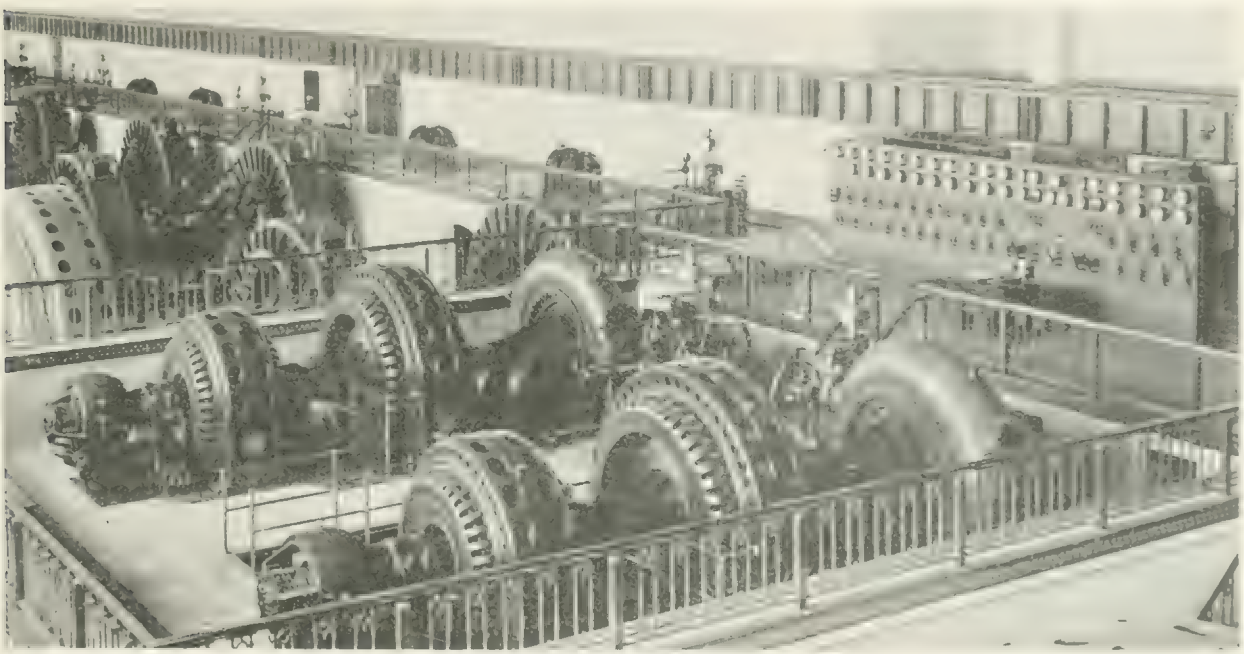

FIG. 1—[illegible] POWER PLANT

The individual motor-generator exciter units are located on the switchboard gallery adjacent to each main unit.

The characteristics which render this system peculiarly well fitted to the conditions, and which led to its adoption, are:—

1—Flexibility.
2—Safety.
3—Reliability.
4—Independence.
5—Simplicity.
6—Adaptability to automatic control.
7—Adaptability to distant control.
8—Minimum concentration of low voltage power.
9—Ease of distribution of power.
10—Adaptability to an existing plant.

While the advantages of the system finally adopted over those of any of the other systems considered were, for this installation, so marked as practically to determine the choice, its cost was nevertheless care-

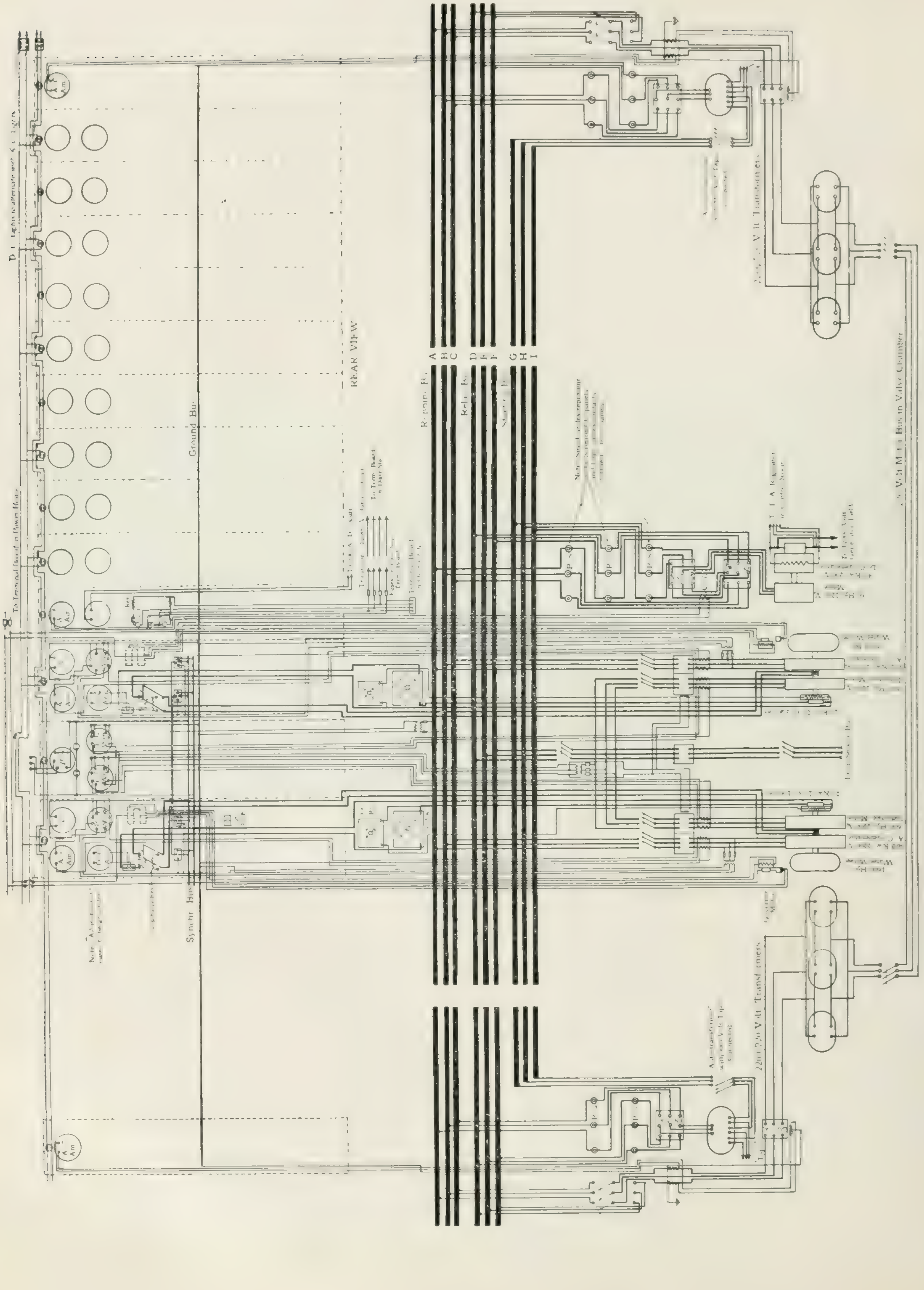

FIG. 2—WIRING DIAGRAM OF EXCITER POWER PLANT

fully investigated. These cost studies were decidedly favorable to the system adopted, not only in comparison with other individual systems but also with the suggested central direct-current system.

The new system as installed at the Ontario Power plant consists of the following four elements:—

1—The exciter power plant, comprising penstocks, turbines, governors, generators and motors, providing a source of power entirely independent (except as to the source of the water) from the main power units.
2—The switchboard containing the necessary switches, etc., for controlling the power from the exciter power plant and distributing it.
3—The individual unit exciters consisting of induction motor-generator sets located adjacent to their respective main units.
4—The regulating devices, including Tirrill regulators, power-factor and line drop compensators and relays.

EXCITER POWER PLANT

The exciter power plant contains two units each consisting of a 1 600 hp, 375 r.p.m. Francis type hydraulic turbine driving a 900 kw, three-phase, 25 cycle, 2 200 volt alternating-current generator. On the same shaft is also a 600 hp, three-phase, 2 200 volt induction motor capable of carrying the full load of the generator for a period of ten minutes. This motor is arranged to be connected through suitable transformers to the main 12 000 volt station busses, and is intended as an instantaneous relay on the turbine. It is started by means of the turbine by driving the unit to synchronous speed and closing the supply switch; thus no special starting devices are required. The shaft also carries the exciter for the 2 200 volt alternating-current generator. Each of the two units is capable of carrying the entire exciter load of the station. They are located on a walled gallery somewhat above the main floor of the station and near its ultimate center, as shown in Fig. 1.

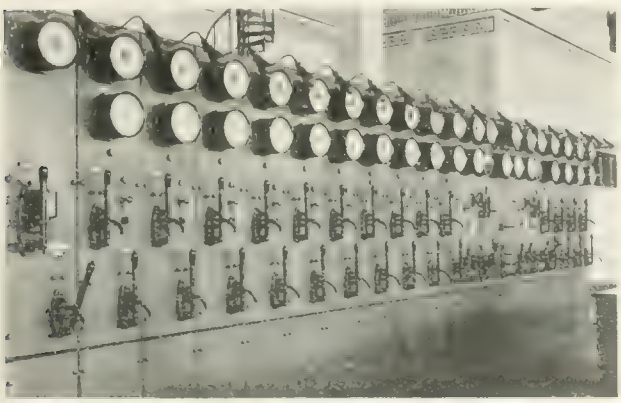

FIG. 3—EXCITER SWITCHBOARD

EXCITER SWITCHBOARD

On and under the main gallery of the station, immediately adjacent to the main exciter power plant is located the switchboard for the control and distribution of the excitation power. The power is controlled through oil switches mounted in cells beneath the gallery with remote hand control from the switchboard proper on the gallery directly above.

The connections are shown in Fig. 2. There are three busses mounted on pipe framework above the switch cells, a starting bus, a running bus and a relay bus. The running bus is fed from the exciter power plant and the relay bus from the main 12 000 volt busses through the same transformers which furnish power for the 600 hp induction motors. The starting bus may be fed through either of two reducing auto-transformers from either the running or the relay bus by means of double-throw switches. The individual exciters are fed through double-throw switches from either the running bus or the relay bus, as desired, and double-throw starting switches are provided for each individual exciter which transfer the exciter motor from the starting bus to whichever of the two power busses has been selected.

The switchboard is of black Monson slate with dull finish and presents a very neat appearance, as shown by Fig. 3. It contains the necessary instruments for controlling the exciter plant and, also, for each main unit, two alternating-current ammeters, one showing the current input to the individual exciter motor, the other the current output from the main 12 000 volt generator. These are merely for the information of the switchboard attendant, the control of both individual exciters and generators being handled from the main control room in the distributing station.

INDIVIDUAL EXCITERS

From the switchboard iron conduits convey the power in three-phase, 2 200 volt, lead-covered cables underneath the gallery to the individual exciter motor-generator sets located on the gallery adjoining their respective main units. These are of two sizes for adaptation to the different generators, some being of 40 kw output and some of 60 kw. Each exciter is of sufficient capacity for one generator only and a spare set is kept on hand to replace any one which may be in trouble, the process of changing requiring only a few minutes. The exciters have a synchronous speed of 750 r.p.m. The individual exciters are mounted on the station gallery in order that all the auxiliary apparatus likely to require attention shall be so placed, the governors of the main units and the generator oil circuit breakers also being located here. This is a decided advantage in operation. The entire 2 200 volt system is designed for and subjected to a test of 10 000 volts between live parts and ground, this extra high voltage test being for the purpose of establishing a very high factor of safety in the insulation.

From the direct-current terminals of the individual exciters the main field leads run directly, without either switch or rheostat, to the collector rings of the main generators. Thus, the exciter is virtually a part of the main generator, the entire control of the main field current being effected through the field of the exciter. The exciter generators are shunt-wound, with series-wound interpoles which assist them to

commutate perfectly at all loads and voltages at which they can be operated.

From each individual exciter a small four-conductor leaded cable extends to the control room in the distributing station, a distance of about 1 000 feet. Two of these wires are connected across the direct-current terminals of the exciter and carry the direct-current potential to the voltage regulators. The other two are the exciter field leads, connecting the field with the field rheostat and regulator in the control room. These four wires are insulated rather more highly than usual for 250 volt wires, and otherwise are especially protected against interference or damage.

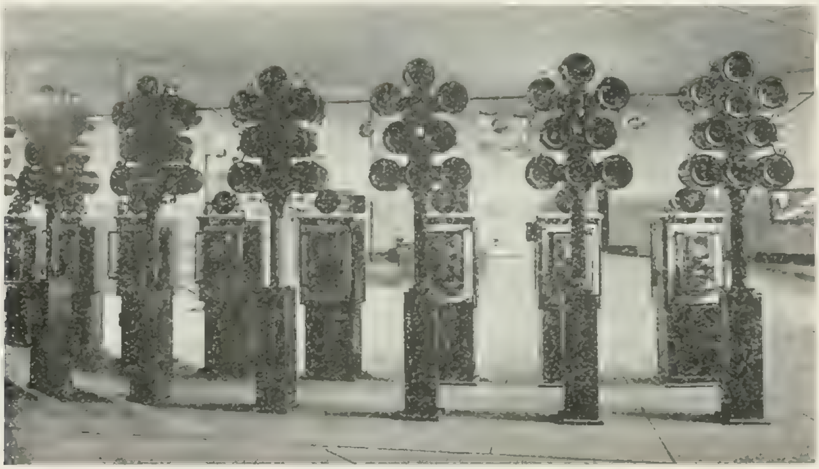

FIG. 4—CONTROL ROOM
Rear view of control stands and instrument posts, showing voltage regulators.

FIG. 5—REAR VIEW OF CONTROL STAND

VOLTAGE REGULATORS

In the control room the regulators and relays are mounted on the rear of the individual control pedestals, Figs. 4 and 5, with the necessary control switches, rheostat handles, etc., on the front, as shown in Fig. 6. The exciter field rheostats in conjunction with which the regulators operate are mounted below the control room floor. They are of the ratchet-driven type and are controlled electrically by means of the controller switch originally provided under the old system for operating the main field rheostats.

The regulators themselves, except for a few special features in the mounting, are standard. The white Italian marble panels on which they are mounted are hinged to the stands, thus forming rear doors for access to the interiors of the pedestals and also enabling a regulator to be swung about so as to face the operator, as shown in Fig. 6, in case it should require special observation for any reason. The connections of the regulators and auxiliary apparatus are shown in Fig. 7. The operation of the Tirrill regulators is now too well known to need description here and, therefore, attention will be confined to the operation of the

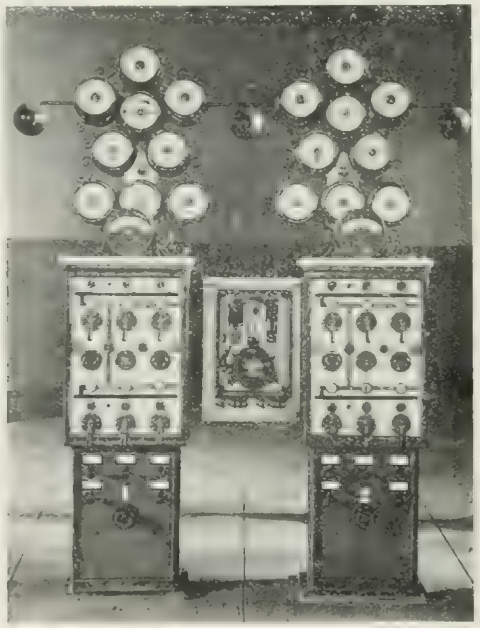

FIG. 6—FRONT VIEW OF CONTROL STANDS
Showing one regulator swung around to face the operator.

special compensating devices and relays used in conjunction with the regulators.

POWER-FACTOR COMPENSATORS

As above stated, the key to the successful operation of the system here described is contained in the power-factor compensator which performs the function of equalizing and stabilizing the division of wattless current among the generators. It becomes apparent, on analyzing the problem, that to produce such stability it is necessary to regulate not only the voltage, but the phase angle of the current with respect to the voltage. It is a well known fundamental principle of regulation that variation of the function to be regulated must produce or release the regulating or restoring force. Thus the regulation of power-factor or phase angle of current must be accomplished by some device responding to this function. Probably the result could be accomplished in some way by means of a contact making power-factor meter, but as both the voltage and power-factor of alternators in multiple are fixed by their field charges, the result can be accomplished in a much simpler way by applying the proper force directly to the regulator itself which controls the field charge.

In the final analysis, a voltage regulator tries to keep constant the mechanical force exerted on the moving element of its alternating-current magnet. Under ordinary conditions this force is produced solely by the voltage of the system. In order to make such a regulator maintain constant phase angle between current and voltage, therefore, there is required to be added to the force already applied to the moving element, a small transient force equal to zero (or practically so) when the phase angle has the desired value, but increasing in a positive or negative direction as the phase angle decreases or increases. Such a force will cause the regulator to vary the field charge

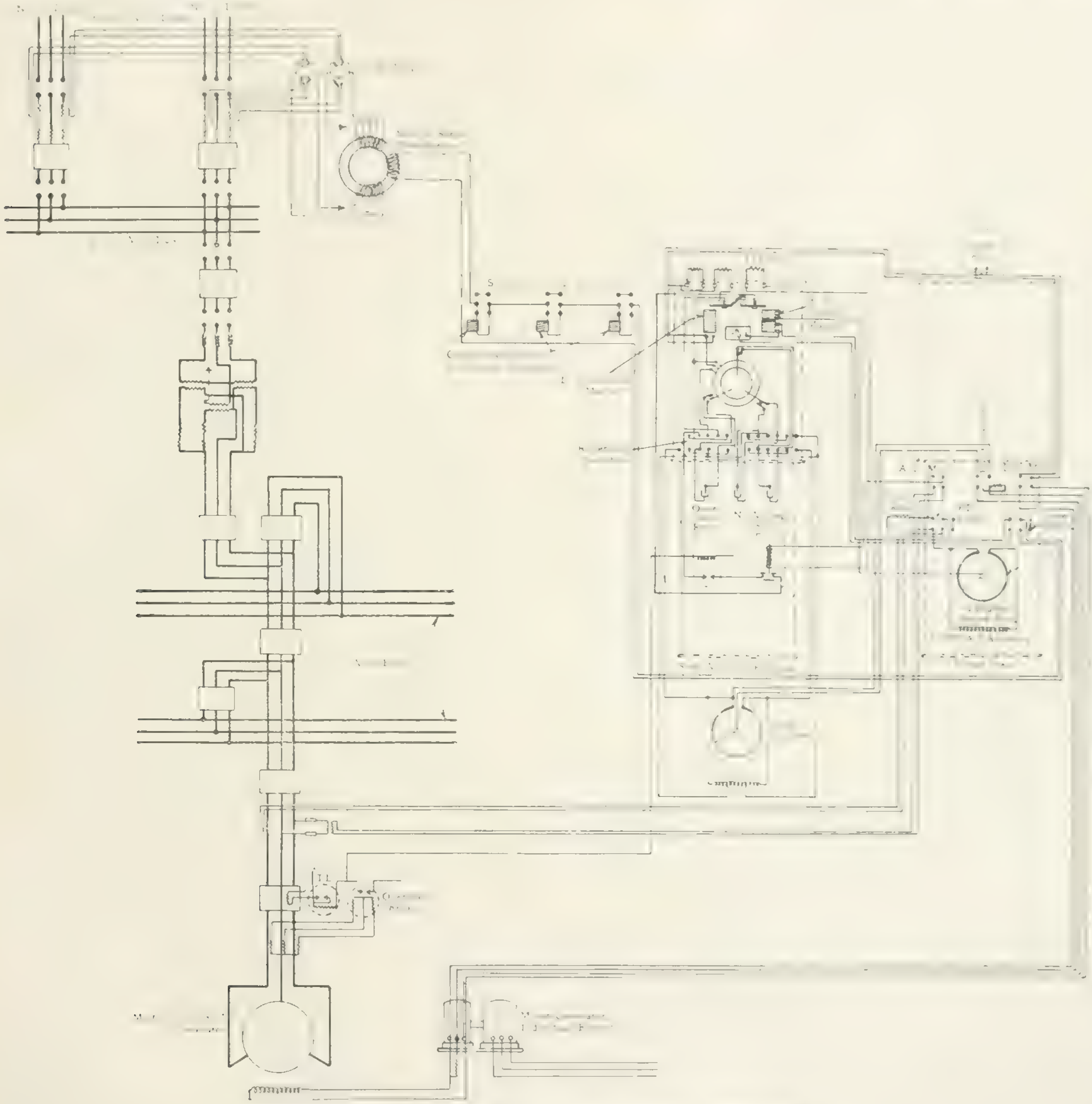

FIG. 7 — WIRING DIAGRAM OF INDIVIDUAL VOLTAGE REGULATOR

of the generator so as to restore the phase angle of the current to its established value, and the restoring force will gradually fall to zero as the normal condition is restored.

Such a force may be produced (practically) with unity power-factor by a current in quadrature with the voltage, and varying in phase position with the

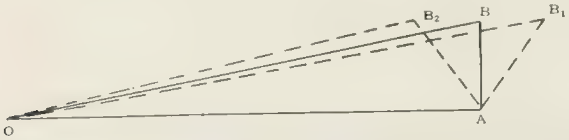

FIG. 8—DIAGRAM SHOWING ACTION OF POWER FACTOR COMPENSATOR IN CONNECTION WITH AUTOMATIC VOLTAGE REGULATOR

OA = current, flux, or pull due to voltage.
AB = current, flux, or pull due to compensator with no wattless current.
OB = resultant current, flux, or pull which regulator tries to keep constant.
AB_1 = transient current, flux or pull in compensator due to increase in lagging wattless current.
AB_2 = transient current, flux, or pull in compensator due to increase in leading wattless current.
OB_1 and OB_2 = transient resultant current, flux or pull immediately restored to condition OB by regulator action.

line current, as the resultant of this force and that produced by the voltage differs by a very small amount from that produced by the voltage alone, while with a change in the phase angle of the current the resultant force increases or decreases very rapidly. This action is illustrated by Fig. 8. In a three-phase system at unity power-factor such a current may be obtained from the phase to which the regulator potential coil is not connected or by proper connection of series transformer secondaries in the other two phases. The quadrature current can be applied to produce the required mechanical force on the alternating-current moving element either by passing it through a resistance connected in series with the alternating-current regulator circuit—which is the method used in this installation—or by passing the current directly through an auxiliary compensating winding upon the alternating-current magnet. In the first case the result is obtained by vector addition of currents and in the second of fluxes.

In the preliminary experiments the quadrature compensating current was obtained from an interconnecting circuit joining the two groups of generators and feeders, so that it was possible to maintain the power-factor of this interconnecting circuit at unity, giving ideal operation of the compensating device. But by inserting in the alternating-current regulator circuit a variable resistance it was found quite possible to maintain the power-factor of this circuit at any desired value (within practical limits), thus demonstrating that the device was perfectly adaptable to individually regulated generators operating in parallel at power-factor other than unity. The following analysis will serve to make this clear:—

The simplest application of the power-factor compensator consists in the use of a compensator coil, acting on the core of the alternating-current coil of the regulator, in which would flow a current which, at unity power-factor load, would be in quadrature with the voltage and hence with the current in the A.C. coil on the regulator. This current would be taken from a series transformer in say, phase A, the voltage being taken across phases B-C. The regulator regulates to a constant pull on the core of the A.C. coil. If positive or negative pull is supplied from some source other than the A.C. coil (such as the compensator coil) the voltage decreases or increases until the total pull on the core is restored to its normal value. With unity power-factor the resultant flux (or pull) would be the sum of a large flux and a very small one in quadrature with it, hence the full-load voltage would be only slightly less than that at no load, as shown in Fig. 9. With lagging power-factor the compensator current is thrown around partially into phase with the voltage (or A.C. coil current) and is so connected as to assist the pull of the coil. The voltage then decreases until the pull is restored to normal, as shown in Fig. 10. With leading power-factor there will be an increase in voltage in a similar manner, as shown in Fig. 11.

In operation there are three cases to be considered:—

I—Operation of one machine alone.
II—Operation of any number of machines in parallel.
III—Operation of any number of machines in parallel with one machine uncompensated.

In Case I the voltage varies with the power-factor, increasing as the power-factor increases (on the lag side) and decreasing as it decreases. This variation may be very small. The voltage also varies slightly with the load, decreasing with increase of

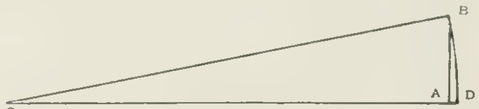

FIG. 9

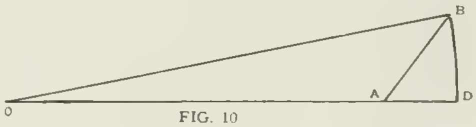

FIG. 10

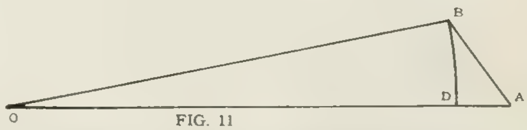

FIG. 11

FIG. 9—REGULATION DIAGRAM—NO WATTLESS CURRENT
FIG. 10—REGULATION DIAGRAM—LAGGING WATTLESS CURRENT
FIG. 11—REGULATION DIAGRAM—LEADING WATTLESS CURRENT

OA = Pull of voltage coil.
AB = Pull of compensator.
OB = Resultant pull, regulated.
AD = Regulation.

load at unity and lagging power-factors, and increasing with increasing load at leading power-factors. In case of loss of load the voltage varies by an amount depending upon the power-factor, amount of compensation and initial load.

In Case II the additional condition enters of inter-action between generators. Assuming that all are

adjusted alike, any attempt on the part of one machine to deliver more wattless current than the others, that is, to deliver its power at a lower power-factor, results in a decrease of the field charge of that machine, thus restoring equilibrium. As this reduction of field charge is caused through the agency of the excess wattless current itself, that is, by the increase in phase angle of the current, it ceases as soon as the excess disappears. The simultaneous action of the other machines is exactly reverse, thus assisting to the final result. For adjustment, and to provide for operating different machines at different power-factors if desired, variable resistances may be placed in series with the alternating-current coils. Both voltage and power-factor distribution would be controlled by these resistances. By making the relative ampere-turns of the compensator small as compared to the coil, the rise of voltage on loss of load may be kept as small as desired. The device will be stable, no matter how small these values, as the further the power-factor (or phase angle) departs from the value

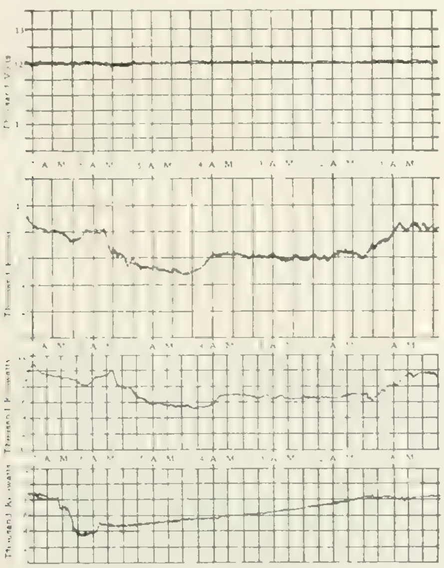

FIG. 12—VOLTMETER AND GENERATOR WATTMETER CHARTS
Showing regulation with individual regulators.

for which it is set (provided it does not pass beyond zero) the stronger is the force acting to restore it. The rise of voltage on loss of load will be equal to that percentage which the resultant additional pull of the compensator current on the core is of the pull of the voltage current. The voltage variation due to load and power-factor variations will be less than that due to a total loss of load, and hence can be made very small.

In Case *III* there will be no compounding action provided the variations in the demand for wattless current are not greater than one generator can readily take care of. With this scheme the bus voltage is maintained constant by the machine operated without the compensator. The regulators on the other machines, being compensated, maintain constant power-factor, hence variations in wattless current are thrown onto the uncompensated machine. Unstable interaction between machines is impossible as all the compensated machines are constrained to act each in the same manner toward the uncompensated one and also toward each other.

In the Ontario Power Company's installation the quadrature compensating current is obtained from the third phase of the generator circuit and is utilized by passing it through a small resistance in series with the potential circuit of the regulator. There is also connected in series with the alternating-current regulator circuit, a variable resistance. With the generator operating alone this variable resistance serves to vary the relation between current and voltage in the alternating-current coil and hence to vary the voltage of the generator.

With the generator operating in parallel with others, variation of the series resistance changes the voltage only slightly as this is maintained by the other regulators. Its effect, therefore, is to change the power-factor. Thus with several generators in multiple voltage adjustment is effected by changing all the series resistances in the same direction, while power-factor adjustment is effected by changing the relative settings of the series resistances. In fact, these series resistances are used exactly as field rheostats are ordinarily used.

The system is operated in accordance with Case *II*, i. e., with compensators on all machines. The character of regulation obtained is shown by Fig. 12 in which a graphic voltmeter chart is shown together with the load charts of the three machines supplying the load. Results with the individual regulators are even better than were obtained with the group regulators previously employed.

LINE DROP COMPENSATORS

In addition to the power-factor compensation, which is an inherent and necessary part of the system, the regulators are also equipped for line drop compensation.

On account of the multiplicity of regulators the use of the ordinary line drop compensator of the Mershon type is not practicable, as the number of generators to be compensated for the line drop is constantly changing, and each number would require a different setting of the compensator on account of the variation of the resistance of the compensating circuit when the individual regulators were cut in or out.

To overcome this difficulty a system was devised of obtaining a compensating current which would be independent of the resistance of the compensating circuit. The fundamental principle of line compensation is the creation of a current proportional both in value and phase relation to the line drop which is to be compensated for. Such a current will necessarily be proportional to the line current, and at a certain phase angle therewith, depending upon the line constants. Any method therefore of producing such a current may be used to produce line compensation. It is evident that if varying proportions of the

currents in two phases of the line can be combined to produce a single resultant, this resultant may be made to have any value and phase position desired. This may be accomplished by means of a special series transformer having three windings; two primaries, each of a variable number of turns, and a secondary of a fixed number of turns. In this way a secondary current may be induced having any value and phase angle desired, when the primary windings are supplied from two phases of the line. Thus by proper adjustment, a current can be produced possessing the value and phase relation required for correct line drop compensation. This current, once established, is passed in series through the compensating coils of the regulators of all the generators supplying the load to be compensated, and the number of generators so used can be varied, and the compensating coils of the unused generators cut out, without appreciably affecting the relation between the compensating current and the line current.

In addition to the devices above described there are overload and no-voltage relays whose function is to prevent excessive voltage rises in case of short-circuits and loss of potential on the regulator circuit. Both of these are arranged to open the circuit to the main regulator contacts upon the occurrence of those conditions for which they are designed, thus causing the voltage to fall instead of rise.

The entire plant of The Ontario Power Company has now been operated on this system for a period of several months not only with entire success, but with better results and better satisfaction on the part of the operating force than obtained with the old system. The selection of the individual system has been amply justified by events, in that since its installation it has several times been necessary to subdivide the plant temporarily into as many as five separate sections. This has been done without in the least interfering with automatic control, which would have been entirely impossible with a central excitation system.

A Series-Transformer Tripping Device for Circuit Breakers

B. H. Smith

IT IS well known that a circuit breaker will successfully take care of short-circuits of at least twice its rated capacity if the time of opening is delayed for a few seconds, thus giving opportunity for the initial value of short-circuit current to decrease.* In an experiment to show this, a standard series-trip, time-element relay was used, connected as in Fig. 1. The contacts shunt the trip coil of the circuit breaker and prevent it from operating until the relay operates and opens its contacts. On the first trials the circuit breaker operated perfectly, but on a subsequent test, with current applied to its ultimate capacity, the circuit breaker was destroyed. The reason given was that a speck of some foreign matter had prevented the relay contacts from completely shunting the trip coil and the result was instantaneous action instead of a two-second time element.

Due to the unreliability of operating this type of relay and trip coil from a series transformer it has become standard practice to use a direct-current control circuit whenever possible and to allow the relay to close the contacts and complete the direct-current circuit through the circuit-breaker trip coil. In a large proportion of circuit-breaker installations, however, such as isolated substations, the use of a relay is essential, but a direct-current control circuit is not available except at prohibitive expense and heretofore there has been no satisfactory device for tripping from the series transformer.

Any circuit opening device is subject to arcing and burning of contacts with consequent failure to close properly. Also a relay of considerable power is required in order to keep the contacts firmly closed, and this fact prohibits the use of the otherwise highly desirable and reliable induction-type contact-closing relay. Again "reverse power" relays, which are required in some installations, have inherently a very low torque and cannot be arranged for contact-opening operation.

From the foregoing it is evident that a demand existed for a device which would permit the use of a standard contact closing relay and at the same time allow the power for operating the trip coil to be supplied from the series transformer.

In circuit-breaker operation, if the series transformer circuit is connected simply through a standard trip coil, such as coil *A* Fig. 2, the latter will operate instantly on the occurrence of a predetermined overload. However, if a piece of iron is added below the trip coil plunger and allowed to touch the bottom of the plunger it will be obvious that a few turns of wire, such as coil *B*, Fig. 2, will prevent the plunger from moving no matter how great the current. Then, if a secondary winding *C* of a comparatively large number of turns of small wire is wound over the

*See article on "Breaking Capacity Rating of Oil Circuit Breakers" by J. N. Mahoney in the JOURNAL for Nov 1913, p. 1103

lower coil B as in Fig. 2, but entirely insulated from it, coils B and C may be considered as primary and secondary windings of a small transformer. With the secondary winding open there is a large magnetic flux in the iron, but if the secondary circuit is completed through the relay contacts and current is allowed to flow, it will be in such direction as to oppose the magnetic flux set up by B and reduce it to a minimum. The lower end of the core is thus released, the

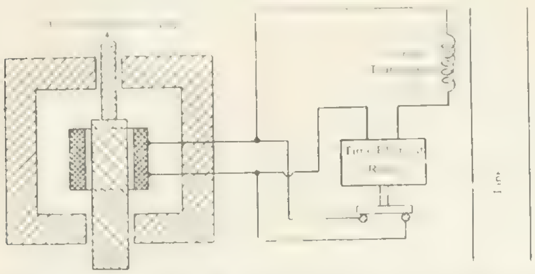

FIG. 1—FORMER METHOD OF TRIPPING FROM A SERIES CIRCUIT THROUGH A TIME ELEMENT RELAY

plunger rises due to the action of coil A and the circuit breaker opens.

One great advantage of the above apparatus is at once apparent, for it will be seen that the instant the core rises away from the lower iron, the current must greatly decrease in coil C and as soon as the circuit breaker opens it ceases entirely; thus the relay contacts are not required to open any current at all. Also, due to the large number of turns in coil C the current ordinarily flowing through the contacts is very small while the e.m.f. is sufficient to overcome any possible

FIG. 3—OPERATING MECHANISM OF A WESTINGHOUSE SOLENOID OPERATED CIRCUIT BREAKER

Showing the method of mounting the series tripping device.

dirt or other resistance. As a result long life and no failures on the part of the contacts should be expected. In fact it seems that the chances of failure from any point in this scheme of operation are extremely remote.

The advantages of this type of circuit-breaker trip may be enumerated in brief as follows.

1—It operates directly from a series transformer in the circuit which it is protecting, thus requiring no separate control circuit.

2—It furnishes positive action, while permitting

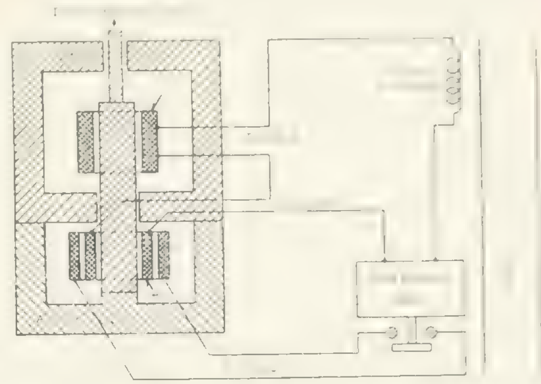

FIG. 2—IMPROVED METHOD OF TRIPPING FROM A SERIES CIRCUIT

the use of accurate and sensitive contact-closing relay, by supplying sufficient voltage to close the contact of the latter against dirt or other possible obstruction.

3—As the action is due to the closing of the relay contacts and as the contacts open no current carrying circuit, there is no sparking, burning or fusing.

4—It allows the use of a type of relay combining a definite maximum time element on short-circuits with the usual inverse time element on ordinary over-

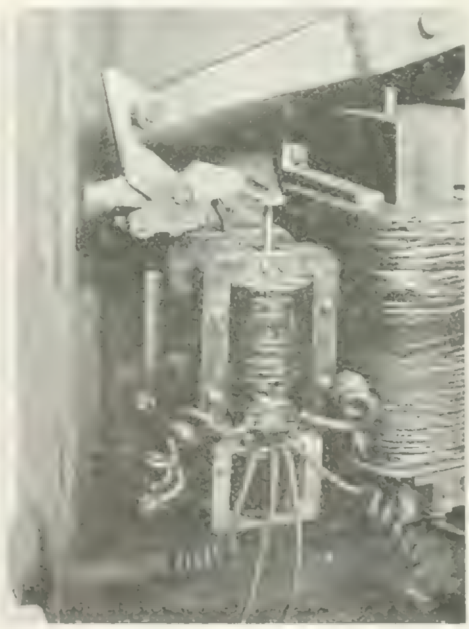

FIG. 4—DETAIL VIEW OF SERIES TRIPPING DEVICE INSTALLED

loads in places where separate control circuits are not available, and thereby decreases the short-circuit current which the circuit breakers must rupture.

Neutralizing Transformers and Their Use in Telephone Circuits

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Engineering Department,
American Telephone & Telegraph Company

THE NEUTRALIZING TRANSFORMER discussed in this paper is a special type of series transformer used for reducing low frequency voltages electromagnetically induced in telephone and telegraph wires by adjacent power circuits. The device is extremely interesting from a physical standpoint and also has proven of great practical service to the telephone and telegraph companies. It has reduced to an endurable amount induction which was so severe and wide-spread as to threaten to put out of use a large amount of telephone plant. While accomplishing such beneficial results, the device nevertheless imposes certain limitations and losses on the circuits used with it. This article discusses the construction and operation of the device, the valuable results accomplished and the limitations and losses imposed thereby.

IN its present development the neutralizing transformer has multiple primary windings and multiple secondary windings serially inserted in the line wires of the disturbed telephone system. The multiple primary windings are associated with a group of telephone circuits known as primary wires, which are grounded at or near the geographical limits of the disturbing parallelism. These grounds complete a low impedance circuit for the induced currents in the primary wires and cause them to magnetize the transformer core. By virtue of the transformer action, electromotive forces are induced in the secondary windings, and by proper connection of the secondary windings with telephone and telegraph wires, which are called secondary wires, these electromotive forces are made to oppose and reduce the voltages induced in these wires by the disturbing electric systems. By virtue of the choke action of the transformer primaries, part of the voltage (90 percent or more) induced in the primary wires acts as an exciting electromotive-force for the transformer primary windings, so that the difference of potential between the ends of the primary wires is reduced by approximately this much.

DEVELOPMENT

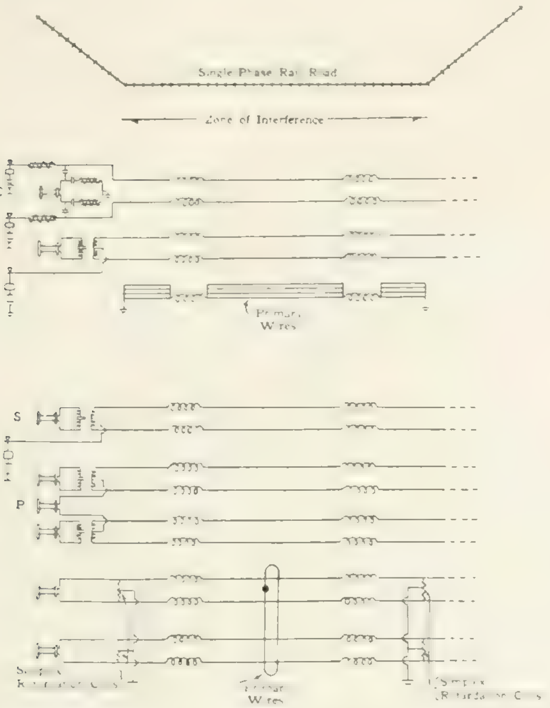
The idea of using series transformers for the purpose of reducing interference in telegraph and telephone lines was due to Mr. Chas. F. Scott, and the development work on the so-called neutralizing transformers was carried out by Mr. Scott and his assistants to a stage which warranted experiments on telephone lines suffering from inductive disturbances. The final adaptation of the neutralizing transformer to the peculiar requirements of telephone service was completed under the direction of the engineers of the American Telephone and Telegraph Company.

The principal incentive for the development of the neutralizing transformer occurred when the single-phase distribution system was proposed for use on the New York, New Haven & Hartford Railroad. (As a matter of fact almost all of the existing neutralizing transformer installations are associated with telephone and telegraph wires paralleling the New Haven Railroad). In the original single-phase system, as applied to interurban electric railroads and the New Haven Railroad, a high-potential, low-frequency trolley current was used, and the return current was allowed to flow partly in the ground. In magnitude, the earth return current was from 20 to 50 percent of the trolley current (depending on the number of tracks and the nature of the earth), and its effect was to induce voltages in the paralleling telegraph and telephone lines. The magnitude of these disturbances was found to be controlled chiefly by the magnitude and distribution of the ground current, and the separation between telephone or telegraph wires and the single-phase railway. (In this connection it is to be noted that serious inductive disturbances have been experienced in paralleling telephone lines five miles away from the disturbing single-phase railroad).

The neutralizing transformer was initially proposed for use on telegraph lines subject to inductive disturbances. In its original conception it had a single primary winding introduced serially into the trolley wire of the disturbing railway, and multiple secondaries inserted serially into the disturbed telegraph wires. The first substantial improvement consisted of the removal of the primary winding of the transformer from the disturbing system and its association with primary wires strung on the same pole line as the disturbed telegraph circuits, and hence having similar exposures. The result of this change was to have the induced voltages in the primary wires at all times substantially equal to those in the secondary wires, irrespective of the position of the load or of the distribution of the return current, thus making it possible for the counter electromotive-forces introduced by the neutralizing transformer in the secondary wires to be more nearly proportional to the voltages induced by the disturbing electric railway, and thus more nearly neutralize them.

The remaining stages of the commercial development work consisted of the adaptation of the neutralizing transformer by the engineers of the telephone company to the special requirements of telephone service. The principal contribution of the telephone engineers consisted of the devising of means for using the primary wires for communication as well as for

neutralizing purposes. Improvements in coil structure were also made. In the early stages of development a single primary winding was used. In order to get a high enough conductivity in the external primary system to insure satisfactory neutralizing action in the transformer it became necessary to use a relatively



FIGS. 1 AND 2—ORIGINAL (UPPER) AND PRESENT (LOWER) METHODS OF PROVIDING PRIMARY WIRES FOR NEUTRALIZING SYSTEMS ON TELEPHONE LINES

large number of wires in parallel. This was very objectionable because of the large reduction in the number of circuits available for commercial telephone service. By using multiple primary windings, however, and by using the general principles involved in the simplexing* of telephone circuits, it was found possible to use the primary wires for telephone purposes without, at the same time, materially affecting their efficiency as magnetizing circuits for the neutralizing transformers. Figs. 1 and 2 illustrate this phase of development. The primary wires, however, are still not available for telegraph service, nor are they as efficient for telephone service as they would otherwise be.

GENERAL THEORY OF NEUTRALIZING ACTION

The ideal aimed at in the design of the neutralizing transformer is to have the counter-electromotive force introduced by it into the secondary wires neutralize the potential induced by the disturbing railway or power line. In practice there will always be unneutralized or residual voltage in the secondary wires for any or all of the following causes:—

1—A phase difference between the voltage induced by the foreign disturbing source and the voltage induced by the transformer due to a corresponding phase difference between the total primary circuit voltage and the voltage acting across the transformer primary.
2—A magnitude difference between the voltage induced by the disturbing source and the counter-electromotive force introduced by the transformer.
3—A wave form difference between the above mentioned voltages resulting from the distorting action of the iron in the transformer core.
4—Alternating-current ground potential differences between the primary ground points.

Fig. 3 (a) illustrates the phase relations in a simple neutralizing transformer system, but with the actual magnitudes and phase angles distorted in order to clarify the diagram. Let E_p, be the electromotive-force acting on the multiple primary windings. I_p, the primary current lags behind E_p, because of the reactance in the transformer. As there is no appreciable reactance in the external primary system, the external primary drop E_{ex} is in phase with the primary current. E the total electromotive-force induced in the primary and secondary wires is the resultant of E_p and E_{ex}. The potential induced by the transformer in the secondary wires is approximately 180 degrees behind E_p, and differs in magnitude from E_p by an amount determined by the transformation ratio of the transformer. It is shown as E_s in the diagram in the same direction as E_p in order to simplify the process of determining the magnitude of the residual voltage E_r. It will be apparent from the diagram that with a given primary system, and a given induced e.m.f., there is a definite ratio between primary and secondary turns which will give a minimum residual voltage. In practice this ratio is not sharply defined because the induced e.m.f., and hence the transformer impedance, varies over a wide range. It will also be apparent that with a given transformer the residual voltage is directly proportional to the impedance of the external primary system. Also, with a given primary system the residual voltage varies inversely with the impedance of the transformer. For this latter reason the iron in the transformer should be worked at low saturations in order to minimize the core loss and the magnetizing current.

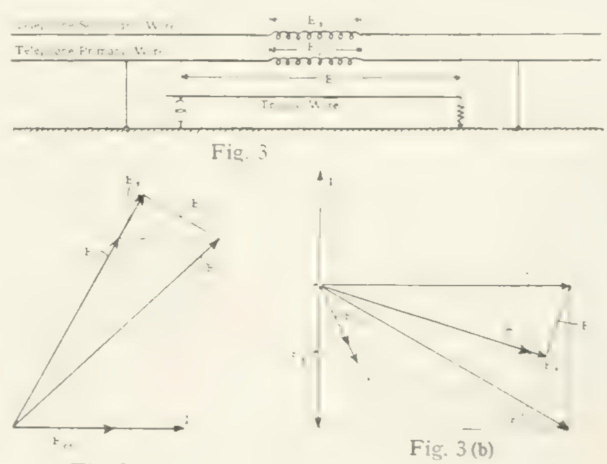


FIG. 3—DIAGRAMS INDICATING INDUCTIVE CONDITIONS AND RELATIONS NEAR A SINGLE-PHASE LINE

*See "The Joint Use of Wires for Telephone and Telegraph Service," by Mr. H. S. Warren, in the JOURNAL for September, 1913.

The problem of reducing the residual voltage in a given neutralizing transformer system to a minimum value is principally one of reducing the phase differences between the electromotive-force acting on the transformer primary winding and the total electromotive-force induced in the primary system. This may theoretically be done in either or both of two general ways though none of these ways has been used in practice in the telephone plant for reasons given later.

1—The external part of the primary system may be designed in such a way as to have approximately the same impedance angle as the transformer, thus making the external primary drop bear the same phase relation to the primary current as the electromotive-force acting on the transformer. This can be done by adding properly proportioned inductance coils to the external primary system.

2—The transformer effective impedance angle may be made to approximate the impedance angle of the external primary system. This can be done by shunting the transformer primary windings with condensers or resistances, so proportioned as to make the transformer with its shunted condensers or resistances approximate the effects of a non-inductive resistance, from the standpoint of the primary system as a whole. Shunted condensers are theoretically preferable to shunted resistances, because of their greater effect in phase adjustments. By choosing proper values of capacity, a parallel-resonance combination with the transformer can be obtained, which acts like a pure resistance as far as external primary effects are concerned.

The use of phase adjusting devices gives best results when the induction conditions are steady. In the practical case, particularly in single-phase induction, the improvement resulting from the use of phase adjusting devices is limited, because of the rapid and great variation in the magnitude of the induced voltage, and because the adjustment which gives best results for one magnitude of voltage does not necessarily give satisfactory results for other magnitudes. Largely because of thes reasons, no phase adjusting devices have been used in connection with any of the neutralizing transformers now installed in telephone circuits.

The use of phase adjusting devices changes the magnitude as well as the phase of the electromotive force acting on the transformer primary winding. Thus if such devices were used it would become necessary to adjust the transformation ratio of the transformer, in order to obtain the best neutralizing action. With series inductances or parallel resistances a larger ratio would be needed than with no phase adjusting device. In this latter case a voltage ratio (secondary to primary) of about ten to nine is commonly required.

Fig. 3 (b) illustrates the phase relations of the potentials and currents when the primary system is influenced by alternating-current ground potentials. The total potential E is induced in the primary and secondary wires, 90 degrees behind the trolley current. The ground potential drop E_g is in phase with the ground current, and approximately 180 degrees behind the trolley current. The resultant of E and E_g is E_t, i. e., the total electromotive-force acting in the primary system. The primary current is I_p. As there is no appreciable reactance in the external primary system, the external drop E_{ex} is directly in phase with I_p. Subtracting E_{ex} from E_t we get E_p, the potential impressed upon the primary. E_s is the electromotive-force induced by the transformer in the secondary wires (rotated approximately 180 degrees from its true position), and E_r is the unneutralized or residual voltage in the secondary wires. It will be noted that the residual voltage in the secondary wires may be less than the alternating-current ground potential acting between the primary ground points. Also, it will be noted that in this case the residual voltage can be reduced by increasing the phase difference between the voltage acting on the primary winding and the total e.m.f. acting in the primary system.

DESIGN OF NEUTRALIZING TRANSFORMER SYSTEMS

Having reviewed the general theory underlying the action of the neutralizing transformer, we are now in a position to consider the questions affecting the detailed design. In this connection it can be stated that neutralizing transformers are designed with special reference to the particular telephone system with which they are to be employed. The reasons for this will be evident from the discussion below.

The electrical proportions of the transformer itself greatly depend upon:—

A—Whether or not superposed telegraph service is involved.
B—The magnitudes of the total induced voltages.
C—The resistance of the primary system external to the transformers.
D—The number of circuits.

A—When the secondary wires are used for simultaneous telephone and telegraph working it is necessary to design the neutralizing transformers and the associated system in such a manner that the residual voltage in the secondary wires will not interfere with telegraph service. It has been found sufficient to set this limit at about 15 volts for the telegraph service which has been involved in the existing installations.

When the telephone toll lines are used solely for telephone business, the neutralization requirements are less severe since larger unneutralized voltages may be tolerated so long as they do not reach magnitudes which bring in hazard to employes, involve appreciable danger to the equipment, or result in excessive maintenance due to the operation of the standard protective devices, which usually ground the circuits in the course of their normal operation and make them temporarily unavailable for commercial service. These considerations have resulted in the compensating transformer systems being so designed for such cases that in times of short circuit or other abnormal conditions in the disturbing system, the induction in the telephone circuits is not substantially over 100 volts. This limit moreover has to be reduced in exchange districts where inductive disturbances of lower magnitudes prevent the use of grounded signaling systems, where the disturbing current brings in noise induction.

Regarding efficiency of neutralization, the best

performance recorded for neutralizing transformers in the plant of the telephone company was approximately a 95 percent reduction for induced voltages in the neighborhood of 200 volts, for which voltage the multi-transformer installation had been designed. At substantially lower voltages the neutralizing efficiency of this particular system was approximately 90 percent, and at higher voltages very much less than 90 percent. The above results were obtained under the most favorable conditions with respect to saturation effects of the telegraph currents superposed on the telephone wires, i. e., the polarities of the telegraph batteries were so arranged that substantially half of the telegraph currents were flowing in one direction and half in the opposite direction, thus having approximately a neutral effect on the transformer core. In the ordinary commercial conditions, which involve duplex telegraph service superposed on the telephone wires, the saturation effects of telegraph currents prevent the neutralizing transformers from working at their maximum efficiency, since it is impracticable to balance the polarities of duplex telegraph circuits with respect to their magnetizing effects upon the core of the neutralizing transformer.

For very high induced voltages it is very difficult to obtain a satisfactory neutralization. As the induced voltages become higher, so must the efficiency of neutralization increase in order to meet the service requirement expressed in the opening paragraph under item *A*, and it is very difficult to obtain an efficiency greater than 90 to 95 percent. When the induction is in the order of magnitude of 1 000 volts, and the efficiency of neutralization in the order just mentioned, it is easily understood that the residual voltages will be large enough to interfere with telegraph operation. This has actually occurred in a telegraph line subject to very severe interference from a paralleling single-phase railway. At times of daily recurring peaks involving values of approximately 1 000 volts, telegraph operation on that line has had to be temporarily discontinued for short periods during the persistence of heavy loads because of the high residual voltage values.

B—The magnitude of the total induced voltage is the factor which determines the number of transformers to be used in a given system, and hence the voltage rating of the individual transformers. From the standpoint of insurance it is desirable to have at least two transformers in series in each important system. From a hazard standpoint it is desirable to have enough transformers in a given system to insure that the potential to ground at any one point will not be large enough to endanger the safety of the employees working on the circuits or the subscribers using the circuits. In this connection it is to be noted that if there are N similar transformers evenly spaced in a system having a uniform exposure, the maximum potential to ground will be one over $2N$ times the maximum potential obtained in the absence of the neutralizing transformers. This maximum potential is located at the transformer terminals. The above considerations result in the transformers being designed to handle a maximum of not over 150 volts each.

C—The resistance of the external primary system—i. e., the primary telephone wires in parallel—has a very important reaction on the electrical dimensions of neutralizing transformers. In order to obtain a high efficiency of neutralization it is necessary to have the transformer primary impedance high in comparison with that of the primary wires. It is not usually practicable to get an external primary of very low resistance for reasons given below, and therefore it is necessary to use high impedance transformers.

The resistance of the external primary system is determined largely by the length of the system and the size of the telephone wires, for there is a practical commercial limit to the number of wires which may be used in parallel, because of the reduced flexibility of the telephone system as explained in section *F*, of the discussion of the limitations of neutralizing transformers. In existing transformer systems in the telephone plant, the total external primary resistances vary from about 50 to about 100 ohms.

D—The electrical and mechanical design of the individual neutralizing transformer is also influenced by the number of circuits in the disturbed telephone system. Questions of size and cost have limited the transformer capacity to about 30 telephone circuits (60 wires). The matter of service protection also comes in. On general principles it is inadvisable to have a large number of circuits associated with a single transformer, since a failure of the transformer would be most disastrous in disorganizing the telephone and telegraph traffic.

General—After the requirements with respect to efficiency of neutralization, voltage rating and number of telephone circuits to be handled by the transformer have been established, and after the external primary impedance has been determined, the detail design of the transformer proceeds much on the same basis as ordinary transformer design. One important difference arises from the fact that the neutralizing transformer operates practically all the time at very light loads, i. e., very nearly in the no load condition. If the neutralization were complete, the only (low frequency) current flowing in the system would be the exciting current in the primary wires. A further important difference is due to the fact that neutralizing transformers have to be designed to work over a wide voltage range. The voltage-current charts illustrated in Fig. 3 (a) and (b) are very useful in the detail design work.

In the design of neutralizing transformer systems, the primary grounding points are located with reference to the terminal of the telegraph circuits carried on the secondary wires and also with reference to the geographical limits of the zone of disturbance. It is practicable to have telegraph circuits

terminated at or beyond the points where the primary wires are grounded, but it is not practicable to have telegraph circuits terminated at points intermediate between the primary grounds. Such conditions would necessarily result in different voltages being induced in the primary wires and the intermediate telegraph circuits by the disturbing system as a result of the different exposures, and consequently the neutralizing transformers would over-compensate the induction in the intermediate telegraph circuits.

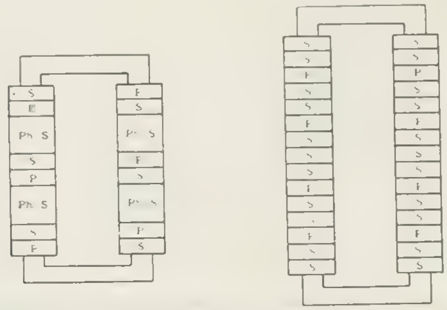


FIG. 4—TYPICAL ARRANGEMENTS OF COILS IN A NEUTRALIZING TRANSFORMER

P—primary; *S*—secondary; *Ph S*—phantom secondary.

In neutralizing transformer systems associated with cable circuits, the primary grounding points are located in central offices near the geographical limits of the disturbing parallelism, and the transformers themselves are installed in central offices.

In open wire lines, the transformers may be mounted on poles, or buried in the ground near the foot of a pole. In such cases the terminal leads are carried in a lead covered cable to a distributing box on the pole, where connections are made to the line wires. This distributing box is also fitted with protective apparatus for the transformer coils. The simplex retardation coils used in establishing the primary grounds are mounted in offices or in weatherproof boxes on poles specially selected with reference to the possibility of obtaining low resistance grounds, while meeting the more general requirements noted above.

CONSTRUCTIONAL DETAILS

The neutralizing transformers are made with silicon steel cores. The smallest commercial neutralizing transformers now in use are built up on standard 10 kw cores, and the largest on 25 kw cores. Each leg of the core has half the total number of primary and secondary coils,—the primary coils being spaced evenly along the core so as to approximate the magnetizing effect of a single distributed primary winding. In transformers having 8 primary coils and 22 secondary coils,—thus having a total of 15 coils on each leg,—the primary coils occupy the third, sixth, tenth and thirteenth positions on each leg. Typical coil arrangements are shown in Fig. 4.

The structure of the individual coils depends upon the type of telephone circuits with which the neutralizing transformer is to be used. When required for ordinary metallic telephone circuits, each coil may have a twin winding such as is illustrated in Fig. 5,—the *A* wire of the pair occupying the odd positions in each odd layer and the even positions in each even layer, its mate the *B* wire occupying the even positions in the odd layers and the odd positions in the even layers. This construction gives a high grade of balance because of the close interleaving of the windings, but it results in a large mutual capacity which is very objectionable from a telephone transmission standpoint. In some of the transformers now in service the mutual capacity of each telephone coil is equivalent to that of about 0.25 mile of the telephone cable circuit with which it is associated. The direct-current resistance per line winding varies from about five to eight ohms.

The primary coils are constructed in the same general way as the secondary coils, except that taps are brought out near the terminals of the primary windings in such a way as to give the voltage transformation ratio which previous calculations have shown to be most desirable. This ratio (working primary turns to secondary turns) is ordinarily in the order of nine to ten. The primary coil construction just described adds to the flexibility of the transformer, since those coils which are not actually required for use as working primary coils may be used as secondary coils. When a neutralizing transformer is designed for use in systems of widely differing characteristics it is sometimes of advantage to have more

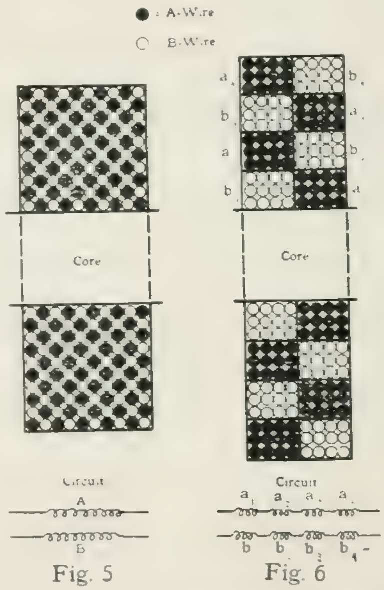


FIG. 5—METHOD OF INTERLEAVING PRIMARY AND SECONDARY WINDINGS TO OBTAIN A CLOSE BALANCE BETWEEN THE TWO

FIG. 6—SECTIONALIZED TRANSFORMER WINDING

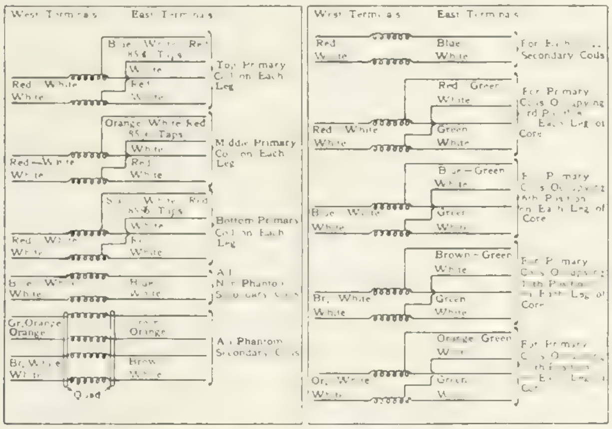
than one set of primary taps brought out so as to give a series of different transformation ratios.

When the neutralizing transformer is designed for use in connection with phantom* telephone circuits, it is necessary to use a type of construction in

*By proper construction and terminating methods, it is possible to establish three independent telephone circuits on four wires. Two of the circuits are on a simple metallic two-wire basis, and are known as "side circuits" because of the fact that with their two wires in parallel they each serve as a side for the (four-wire) phantom circuit.

the transformer coils which will not result in the phantom circuit becoming unbalanced in passing through the transformer. The simplest construction which gives the necessary degree of balance, involves the use of a single quad cable made up of two pairs of wires twisted about one another, so as to minimize crosstalk, or overhearing, between the circuits so associated. This construction also results in a large mutual capacity, which causes relatively large transmission losses in the telephone circuits.

In neutralizing transformer installations where large expenses are warranted in reducing the telephone transmission losses in the transformers, an improved coil structure may be used. This improved construction makes use of sectional windings arranged in the manner illustrated in Fig. 6. By careful manufacture and assembly of the sectional windings a good degree of balance can be obtained, and at the same time the mutual capacity to the associated telephone circuit is reduced to a small amount. Sectional windings may also be advantageously used in transformer coils for



40-Wire Transformer   -Wire Transformer

FIG. 7—TERMINAL CABLE COLOR SCHEMES

phantom circuits. Coils for phantom circuits and non-duplex or simple two-wire circuits may be used on the same transformer without serious mutual interference. Electromagnetic shields are required when sectional windings are used.

Dielectrically, the coils are so constructed that they may be afforded protection by the standard protective devices. Some difficulty is involved in obtaining satisfactory dielectric strength in transformers designed for open wire lines, and hence exposed to lightning disturbances.

The assembled transformer is usually mounted in the pole type of case and weighs from about 300 to about 1 500 pounds, depending on the size. The terminals of the coils are brought out by means of a lead covered cable which emerges from the case at a point near the top of the cover. The conductors in the terminal cable are insulated with a combination of silk and cotton servings, and sometimes also with an enamel film under these fiber servings. The conductors are paired or quadded to correspond with the structure of the coils; i. e., pairs are used in the terminal cable for leading out the two wires of a (non-duplex) two-wire coil, and quads for leading out the terminals of the phantom coils (four-wire coils).

In order to simplify the installation work and assist in the maintenance work, the wires in the terminal cable are colored in accordance with a standard color scheme. A satisfactory color scheme must distinguish

1—Between the [illegible]
2—Between primary and secondary coils, and between 2-wire and 4-wire coils.
3—Between the primary coils in the different positions on the legs of the transformer core, and
4—Between the main terminals and the taps of the primary coils.

Representative color schemes which meet the above requirements are shown in Fig. 7. The purpose of requirement *3* is to make it possible to get the best distribution of primary coils, when less than the maximum number are required for primary purposes.

LIMITATIONS OF THE USE OF NEUTRALIZING TRANSFORMERS

The more important of the limitations of the neutralizing transformer as a neutralizing device, and the limitations imposed by it upon the associated telephone and telegraph circuits are listed and described below. The order in this list is not necessarily that of relative importance.

A—The relief from inductive disturbances is not complete.
B—The scheme is ineffective for reducing noise disturbances.
C—It is impracticable for an exchange plant.
D—The telegraph transmission is impaired.
E—The telephone transmission is impaired.
F—Partial abandonment of the plant is required, in respect to superposed telegraph service.

A—The use of the neutralizing transformer as a remedial device is limited to the reduction of voltages induced electro-magnetically in telephone or telegraph wires by low frequency power systems. The inductive relief is chiefly confined to disturbances at the fundamental frequency and has never been in the nature of a complete relief, i. e., residual voltages are always left on the wires. If the induction is very severe, the residual voltages as previously noted may be great enough to interfere with telegraph service.

B—Theoretically, the neutralizing transformer has possibilities in reducing certain types of noise troubles, but in other types, none at all. In commercial practice, however, neutralizing transformers have not in any case proved to be effective for eliminating noise disturbances.

C—The use of neutralizing transformers in the telephone plant is practically limited to toll lines and cables. They are not practicable for use in the exchange plant (subscribers' lines, etc.), because of the great expense involved—i. e., the cost of the very large number of transformers required and the cost of providing primary wires and associated apparatus. In the above connection it is to be noted that at times of abnormal load—such as short-circuits—disturbances are introduced into large numbers of subscribers' lines

in cities or towns through which single-phase electric railways pass. These disturbances manifest themselves by interfering with the selective signaling systems, and in some cases they operate the telephone protectors and ground the lines, thus rendering communication impossible until repairs are made.

D—From the standpoint of the telegraph service superposed on telephone wires, the neutralizing transformer is objectionable because of its effects in slowing down the telegraph signals and because of the increased crossfire between telegraph circuits carried in the same cable or pole line. The first effect is due directly to the impedance inserted in the telegraph circuits by the transformer windings. The second effect is due to the mutual inductance between the windings of the transformer. These effects are especially serious upon the high-speed systems, such as are now operated by telegraph companies.

E—The neutralizing transformer coils add resistance and capacity to the associated telephone circuits and thereby reduce the telephone transmission efficiency. (No appreciable inductance is added to the telephone circuit because of the non-inductive association of the transformer windings in the two sides of the circuit.) An additional transmission loss is introduced into each primary telephone circuit by the coils used in establishing the primary grounds. The transmission losses resulting from the above causes are especially important on long distance telephone circuits.

F—The use of neutralizing transformers forces the abandonment of superposed telegraph service on the primary wires, which comprise 20 percent or more of the wires passing through the transformers, and restricts the speed of the telegraph service over the secondary wires.

The use of primary wires as telegraph circuits is prevented by the simplex grounds previously referred to, which are required when the interference is at 25 cycles or thereabouts. With higher frequencies (for instance 60 cycles) it might be possible to use resonant circuits in grounding the primary wires, thus avoiding conductive grounds on the circuits and preserving the through conductivity on the line wires which is necessary for telegraph working. Resonant grounding devices at 25 cycles, however, have proved to be impracticable for the reason that they are also near resonance for the telegraph currents, the result being that the telegraph signals are distorted and a large fraction of the telegraph current is diverted to ground by the devices used in establishing the primary grounds.

In conclusion it may be stated that while neutralizing transformers afford means for greatly reducing moderate amounts of low frequency induction, the limitations and disadvantages of such transformers prevent their constituting a primary protection against induction interference. Hence it is necessary, in the case of alternating-current railways, to work out carefully the methods of distributing power to the trains so that inductive disturbances are prevented so far as possible. When this is done, neutralizing transformers have a legitimate and important field in protecting telephone and telegraph service against interference by remanent effects.

A Quality Test for Sheet Insulation

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IN THE COURSE of development of a new type of sheet insulation, it became apparent that no means of accurate discrimination in quality between closely similar samples, was at hand. This was found to be the case after careful trials of the test for dielectric strength and for insulation resistance. The former test, while satisfactory as a comparative test for samples of quite different materials, or as a routine inspection test for failures in a standard process, is not exact and does not repeat closely for a number of samples made by a common process. Furthermore, the insulation being developed was intended for use on voltages much below its breakdown strength.

The resistance tests gave values uniformly very high; the observed heating of the material could not be caused by the minute watt loss due to leakage through the dielectric resistance. It was found that the quality could be roughly judged by the temperature rise under given conditions; but such tests consume a great amount of time and to be conclusive must be pushed to a point where the sample is permanently injured; hence the effect of subsequent treatments such as vacuum drying, heating or the like, cannot be determined. The rise of temperature which occurs in these samples must, of course, be due to watt loss in the sample; hence it was thought that a measurement of this loss would afford the desired information.

It was recognized at the outset that the testing method finally adopted would not be commercial in nature. This was obvious because of the small power loss in the samples, due both to their small size and to their low power-factor. The samples submitted were such that the conducting area would not much exceed 225 square inches and their thickness was not less than one-tenth inch. At a specific inductive capacity of four, the capacity of a sample of this size is roughly 0.002 microfarad. If tested at 10 000 volts (R.M.S), 60 cycles, the charging energy or product of volts by total current would be 75 volt-amperes or

0.075 k.v.a. At one percent power-factor, which would be an average value for samples such as those to be tested, the loss would be only 0.75 watt. Hence any commercial wattmeter test is quite out of the question. Calorimeter tests would not answer the purpose, because the main desire was to be able to obtain curves of watt-loss with time of application of voltage rather than integrated losses over a considerable time. Static wattmeter tests, while possible and quite accurate on large quantities of insulation, would be of little value here because of difficulty in getting accurate knowledge of the ratio between line voltage and the fraction thereof which is applied to the needle of the wattmeter; also the insulation of the wattmeter itself would be a serious problem.

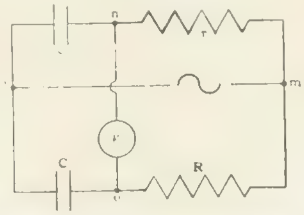


FIG. 1—THE BRIDGE METHOD OF COMPARING CAPACITIES

As this disposes of the commercial methods of measuring power loss, it was seen that a more or less delicate laboratory test would to be required, and for obvious reasons efforts were directed towards developing a null rather than a deflection method.

BRIDGE METHODS OF COMPARING THE CAPACITY AND POWER-FACTOR OF TWO CONDENSERS

Let two condensers be connected in a closed circuit with two resistances as in Fig. 1. Let alternating potential be applied at points *lm;* and a detector of some sort be connected at points *no*. If there is no energy loss in either condenser, or if such energy loss produces equal power-factors in the condensers, the detector *g* will indicate no current when the following relation holds:

$$\frac{c}{C} = \frac{R}{r} \qquad (1)$$

In practice, however, there will be energy losses in both condensers, and they will not have equal power-factors. This means that the phase difference between current and voltage across *ln* will not equal that across *lo,* hence there will be an alternating current through *g,* whether equation (1) holds or not. In this case it will not be possible, by the simple circuit shown in Fig. 1, to obtain a null reading in *g*. There are several means of correcting for this difference of power-factor of the two condensers. Assume that the condenser *C* has more nearly zero power-factor than the condenser *c*. Then the current in the branch *ln* lags behind that in *lo,* while those in branches *nm* and *om* are in phase. To reduce the deflection of *g* to zero, we may either

1—Retard the phase of current in *lo*.
2—Retard the phase of current in *nm*.
3—Advance the phase of current in *om*.

Method 1 may be theoretically accomplished by inserting resistance in series or in parallel with *C*. Method 2 may be accomplished by inserting inductance in series, or in parallel with *r*. Method 3 may be accomplished by inserting capacity in series or in parallel with *R*. The above described methods of obtaining balance, by retarding the phase of current in *lo* or in *nm,* are usually known as the series or parallel resistance or inductance methods of compensating.* Obviously when the current through *g* has by any method been brought to zero, the difference in phase angle between circuits *nm* and *om* equals that between circuits *ln* and *lo*. Hence if three of these phase angles are known, the fourth can be computed.

The next step was the choice of methods of compensation. A glance at the values of capacity and power-factor to be expected in the samples, shows that neither the series resistance nor the parallel resistance methods can be used, because the resistance required would be extremely high—above 50 000 ohms—and must be accurate and free from residual capacity. The series capacity and parallel inductance methods could not be used for a similar reason—prohibitive size and cost of condensers or choke coils. This leaves open only the series inductance method and the parallel capacity method, or combinations of these two. The series inductance method is theoretically to be preferred since the adjustment may be made continuous, and a balance can be quickly obtained. One difficulty is that the alternating-current resistance of the coils used must be known and must be included in the value taken for *r;* this could have been provided for, but the reason for finally discarding this method was the presence of considerable stray fields of synchronous frequency, which made the results unreliable.

PARALLEL CAPACITY POWER-FACTOR BRIDGE

The arrangement finally adopted is shown diagrammatically in Fig. 2. In this figure, *C* represents a condenser of known and variable capacity, and *K* a standard subdivided microfarad, the power-factors of *C* and *K* being known. *R* and *r* represent non-inductive resistances, and *c* the condenser to be tested. This latter consists of the insulation sample, held between two conducting surfaces. An Einthoven string galvanometer is represented by *g*.

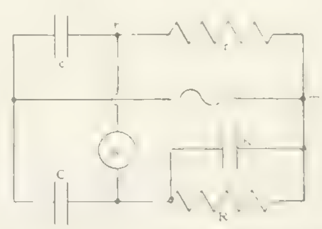


FIG. 2—THE PARALLEL CAPACITY POWER-FACTOR BRIDGE

The routine of making a test is as follows: Connections are made as in Fig. 2, alternating current of proper voltage and frequency being applied at points *lm*. With *K* disconnected, resistances *r* and *R* are varied until a minimum deflection is read on *g*. Then *C* is adjusted until *r* and *R* are as nearly equal and as large as possible when the deflection of *g* is a minimum. Then *K* is connected as shown, and varied

*These methods are fully described by Grover in the Bulletin of the Bureau of Standards, Vol. 3, No. 3, 1907.

until a second minimum is obtained on g. Retaining K at above value, the values of R and r are slightly altered in succession, until a third minimum deflection is found. This final deflection may be made as small as desired, by dividing R and r into sufficiently small steps. When a satisfactory balance has been secured, the values of K, r, R and C are read, and the phase angle of condenser C is found as follows:—

$$\theta_R - \theta_r = \theta_C - \theta_c, \qquad \text{..........}(2)^*$$

where $\theta_R = \tan^{-1} 2\pi fKR$

$\left.\begin{array}{l}\theta_r = 0 \\ \text{and} \quad \theta_C = \dfrac{\pi}{2}\end{array}\right\}$ to a close approximation.

Hence $\theta_c = \dfrac{\pi}{2} - \theta_R$

$$\text{or } \tan \theta_c = \cot \theta_R = \frac{1}{2\pi fRK} \qquad \text{..........}(2)a$$

The percent power-factor of the sample is then $100 \cos \theta_c$.

APPARATUS AND REFINEMENTS

The resistances denoted by R and r, were constructed after designs calculated so that the residual constants of inductance and capacity should balance at a frequency of 60 cycles. Very little trouble has been traced to these residuals. The standard capacity C, is an air condenser of the parallel plate type, specially constructed for high insulation resistance. This condenser is subdivided into 50 divisions of 0.002 microfarads each, which are independently insulated to withstand 15 000 volts, so that the capacity of C may be adjusted to approximate equality with that of c, over a wide range. The condenser K is a standard mica subdivided microfarad, with which, using a value of R between 500 and 6 000 ohms, it is possible to produce any power-factor in the R branch of the bridge, between 0.5 and 90 percent. The Einthoven galvanometer g, was equipped with a stroboscope, driven by a variable direct-current motor. It was impossible on the larger capacities and power-factors to balance the bridge for harmonics, whose presence made the stroboscope essential in determining when the galvanometer string was balanced on the fundamental frequency.

In interpreting the results of tests, it was found in most cases that equation (2a) could be used without serious error. When the result obtained by (2a) showed a power-factor smaller than two percent, the power-factor of the condenser C was added directly to the apparent value so obtained.

VERY SMALL SAMPLES

The above described bridge test when applied to samples of 0.0005 microfarad capacity or less, gave results more or less seriously in error. The actual magnitude of the resistances r and R, as well as their ratio, became important. Apparent variations of power-factor with voltages and with magnitude of the resistances r and R, were encountered, and the power-factor of the standard condenser and of the condenser K, began to affect the accuracy of the results. All discrepancies whose cause is not mentioned above were finally traced to capacity from different parts of bridge to other parts and the ground. Much better results were obtained by the use of a third condenser, using a substitution method as outlined by Grover. The testing method and apparatus is being further developed to adapt it to power-factor measurements on extremely small samples of insulation; also for differences of power-factor of 0.1 percent or less.

*The proof of equation (2) is as follows:
Consider the resistance r to be not non-inductive, and the capacity C to be imperfect. Represent the residual capacity of r by a parallel condenser k as in Fig. 3. Consider the

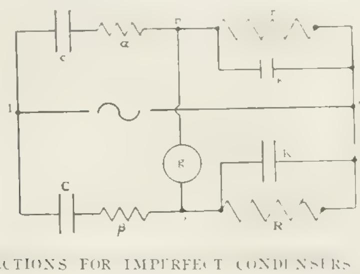


FIG. 3 CORRECTIONS FOR IMPERFECT CONDENSERS AND RESISTORS

power-factor of condensers c and C to be caused by series resistance a and β respectively. The quantities a, β and k, are fictitious, and are introduced merely for convenience in developing equations.

When the arrangement of Fig. 3 is balanced, we have as is well known:

$$\frac{Z_{ln}}{Z_{lo}} = \frac{Z_{nm}}{Z_{om}} \text{ or } Z_{ln} = \frac{Z_{nm} Z_{lo}}{Z_{om}}$$

The impedances denoted by Z_{ln} etc., are as follows:—

$Z_{ln} = \alpha - jx$, where $x = \dfrac{1}{2\pi fc}$

$Z_{lo} = \beta - jX$, where $X = \dfrac{1}{2\pi fC}$

$Z_{nm} = \dfrac{1}{\dfrac{1}{r} + \dfrac{j}{y}}$, where $y = \dfrac{1}{2\pi fk}$

$Z_{om} = \dfrac{1}{\dfrac{1}{R} + \dfrac{j}{Y}}$, where $Y = \dfrac{1}{2\pi fK}$

Hence the following equation is true:

$$\alpha - jx = \frac{\dfrac{1}{R} + \dfrac{j}{Y}}{\dfrac{1}{r} + \dfrac{j}{y}} (\beta - jx) \qquad \text{..........}(3)$$

Equating real terms of equation (3)

$$\alpha = \frac{\beta}{Rr} + \frac{\beta}{Yy} + \frac{X}{rY} - \frac{X}{Ry} \qquad \text{..........}(3a)$$

Equating imaginary terms of equation (3)

$$-jx = j\left(\frac{\beta}{rY} - \frac{\beta}{Ry} - \frac{X}{Rr} - \frac{X}{Yy}\right) \qquad \text{..........}(3b)$$

Dividing (3b) by (3a)

$$\frac{x}{\alpha} = \frac{\dfrac{\beta}{Ry} - \dfrac{\beta}{rY} + \dfrac{X}{Rr} + \dfrac{X}{Yy}}{\dfrac{\beta}{Rr} + \dfrac{\beta}{Yy} + \dfrac{X}{Ry} - \dfrac{X}{Ry}} \qquad \text{..........}(4)$$

Divide the right hand member of (4) by β, multiply it by Rr, and divide it by $1 + \dfrac{Rr}{Yy}$, and (4) becomes

$$\frac{X}{\alpha} = \frac{\dfrac{\dfrac{r}{y} - \dfrac{R}{Y}}{1 + \dfrac{Rr}{Yy}} + \dfrac{X}{\beta}}{1 - \dfrac{\left(\dfrac{r}{y} - \dfrac{R}{Y}\right)}{1 + \dfrac{rR}{Yy}} \dfrac{X}{\beta}}$$

$$\text{or } \tan \theta_c = \frac{\tan(\theta_r - \theta_R) + \tan \theta_C}{1 - \tan(\theta_r - \theta_R) \tan \theta_C}$$

$$\text{or } \tan \theta_c = \tan\left[(\theta_r - \theta_R) + \theta_C\right]$$

$$\text{hence } \theta_C - \theta_c = \theta_R - \theta_r \qquad \text{Q. E. D.}$$

The ratio between capacities of C and c and resistances R and r may be obtained from (3a) if desired.

Protection of Telephone Circuits

W. A. Darrah

THE SUBJECT of the protection of electrical equipment, like the closely allied subject of insurance, is surrounded by so many variables that much confusion exists in connection with it. When, in addition to the apparatus, the lives and property of the public are involved, the problem becomes exceedingly complicated. Under these conditions attention is directed primarily to protecting the public and its property. This is especially true of telephone circuits, the protection of which may be said in a true sense to be insurance. The present article points out briefly some of the essentials in the protection of telephone circuits and, as this subject is entirely different and requires a method of attack not encountered in the protection of power circuits, some space is devoted to the elementary principles involved.

LIKE the protection of power circuits, the object of applying protective apparatus to telephone circuits is to reduce the hazards to life, instruments and property which may result from outside electrical sources. These sources of hazard may be classed under two general heads, as follows:—

1—Those foreign wires whose voltage, current and other characteristics are such that it is feasible to so construct and protect telephone circuits as to provide reasonable safety in cases of accidental contact of the telephone circuits with the foreign circuits; and

2—Those foreign wires whose voltage, current and other characteristics are such that it is not feasible to so construct and protect telephone circuits as to provide reasonable safety in cases of contact of the telephone circuits with the foreign circuits.

The above classification has been adopted mainly because the exposures to which telephone lines are subjected follow these general lines. Many rural lines, specially in those parts of the country not yet crossed by a network of transmission lines, require protection from atmospheric disturbances only. This is a hazard to telephone lines which may be included in both of the above classes.

Practically all town or city telephone lines are exposed to trolley circuits, alternating-current distribution circuits and constant-current arc lighting circuits against which reasonable protection may be expected; thus they fall under the first classification and probably include the larger part of all circuits.

The second classification is intended to include exposures to high potential transmission circuits and is regarded as extra hazardous, most of the telephone companies refusing to connect circuits so exposed to their own lines without very special precautions. Telephone circuits carried on the same towers as high potential circuits are the best examples of this class of exposure, and are found in operation by almost all power transmission companies. Mechanical protection by means of a series of networks or guards at crossings and a line construction such as to provide a considerable distance between the circuits, reduces the hazards for lines thus exposed; and electrical devices are also employed as will be described later.

The second class also covers exposures to alternating electromagnetic and electrostatic fields from adjacent railway or transmission circuits. Such fields may induce high potentials (sometimes as much as 1 000 volts) upon the telephone circuit, may cause large circulating currents, or may merely cause the circuit to be noisy. These difficulties can be mitigated by sectionalization of the lines, transpositions in the telephone circuits and in the power circuits, drainage coils, compensating transformers, shields and various other devices. Many of these are not, however, suitable for commercial telephone circuits.

PROTECTIVE DEVICES

Three essential elements which include the principal components of protection for telephone circuits against the hazards listed above, are as follows:—

1—Open space cutouts—sometimes called spark gaps.
2—Heat coils.
3—Fuses.

The function of the open space cutout is to provide a path of low dielectric breakdown between the line and the ground, acting in this manner very similarly to a safety valve. The usual construction is to arrange two conducting blocks with parallel surfaces closely adjacent to each other and so adjusted that potentials in excess of a given value will pass from the line to one block, across the gap to the second block and then to ground.

The heat coil is a device provided to ground the line, or sometimes to open the circuit, and occasionally to do both, in case small currents circulate from the line through the telephone apparatus for a given period. The heat generated by these small continuous currents passing through the coil causes a soldered joint to be released—thereby allowing a spring to operate and perform the functions for which the coil is designed. In addition to grounding the line, the spring which the coil releases frequently closes an additional circuit, thus operating an alarm. It will be obvious that the object of the heat coil is to prevent the small continuous stray currents referred to above, from burning out the delicate telephone apparatus by reason of the cumulative heating effect.

Telephone fuses are designed to open the circuit only in case the foreign currents flowing on a telephone circuit (as in the case of a cross with a power circuit) are of sufficient size to overheat the telephone conductors. As will be later explained, it is undesirable to operate a telephone fuse for other reasons and no protection is expected from the fuse in the way of preventing damage to telephone apparatus. The object of preventing the overheating of the telephone circuit is, of course, to eliminate fire hazards.

DIVISION OF APPARATUS FOR PROTECTION

There are three general divisions of telephone apparatus requiring protection as follows:—

1—Subscriber station apparatus.
2—Central office (telephone exchange) apparatus.
3—Cable—submarine, underground and aerial.

Subscriber's Station Protection—Considering first the protection of the subscriber's station apparatus, which is only exposed to lightning or atmospheric disturbances, all that is necessary is to provide an open space cutout. The conducting blocks which form the cutout in this case, are most economically

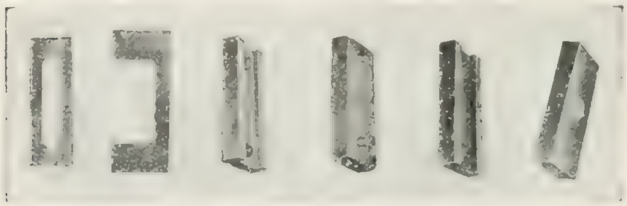


FIG. 1—TYPICAL FORMS OF BLOCKS USED IN OPEN SPACE CUTOUT PROTECTION OF TELEPHONE CIRCUITS

The two blocks in the center are of metal and the right hand two are of carbon, the figures on the left being typical mica separators.

(from a maintenance standpoint) made of metal. Good results have been secured when both blocks are of copper, or when one block is of copper and one of brass. A uniform separation of 0.005 inches with a total permissible variation of 0.0005 inches is commercially secured by means of a mica sheet. Fig. 1 shows some typical forms of carbon and metal blocks while Fig. 2 illustrates the usual circuit connections.

Carbon block open space cutouts with an air space the same as that of the metal block cutout referred to above, discharge at a somewhat lower average voltage than the metal block cutout. When the only exposure of the telephone line is to atmospheric disturbances, however, the metal block cutout described furnishes adequate protection and is less difficult to maintain than a carbon block cutout with the

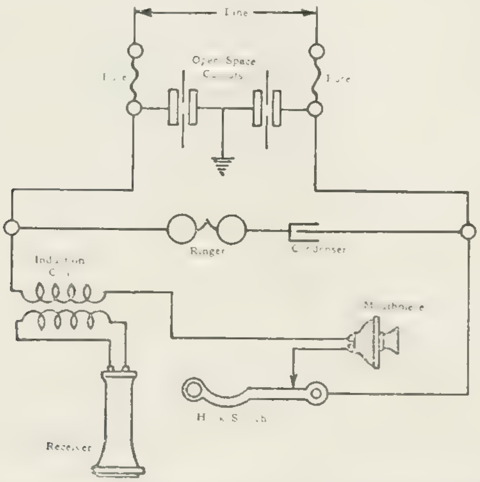


FIG. 2—DIAGRAM OF CIRCUITS OF A COMMON BATTERY SUBSCRIBER'S STATION

Showing apparatus for protection from lightning and power and lighting circuits.

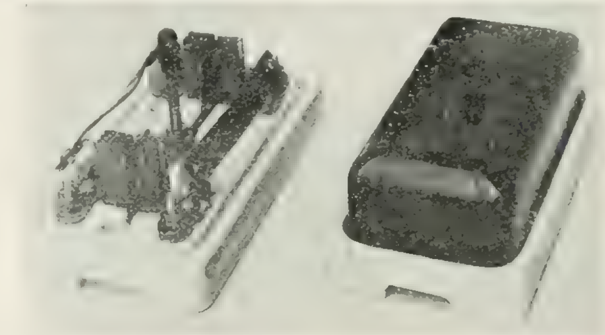
same length of air gap. This is due to the trouble which occurs in the latter from carbon particles torn from the surface, which accumulate in the small gap and form a variable resistance path to ground.

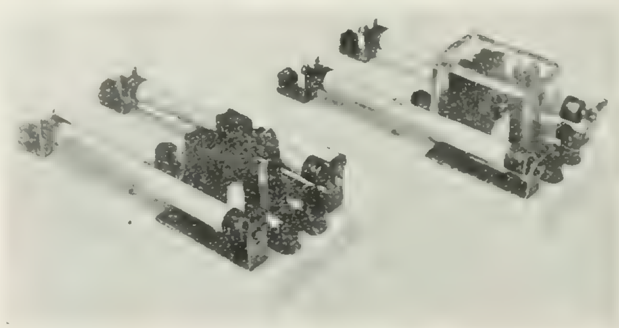
Considering next the case of the protection of subscriber's station apparatus from such sources as referred to in the first classification of hazards above, two conditions require consideration:—

1—The so-called common battery circuit, in which a condenser is provided to prevent the circulation of small currents through the telephone apparatus, and

2—The case in which the signaling apparatus (telephone ringer or bell) is normally connected directly across the line and thus exposed to small currents which may circulate for intervals through the signaling apparatus. The magneto, or hand generator station, is an example of the latter type, as are many private telephone circuits used by various operating and public utility companies.

The standard protection which is employed in Case *1* comprises two open space cutouts, each made up of two carbon protector blocks and two fuses. This apparatus is usually grouped together in some suitable mounting—examples of which may be seen in Figs. 3 and 4. This combination discharges at potentials of 450 volts or over, thus giving protection





FIGS. 3 AND 4—TYPES OF PROTECTORS USED FOR COMMON BATTERY SUBSCRIBER'S STATION

from the average trolley circuit. One of the carbon blocks is provided with a plug of fusible metal, inserted in the center of the sparking surfaces and designed to melt in case an arc is maintained between the blocks—thus connecting the line block with the ground block and eliminating the possibility of setting fire to the structure in which the protector is placed.

The fuses employed in this case are rated at seven amperes (i. e., to carry seven amperes continuously) and will operate on currents 50 percent in excess of this value within five minutes. It will be evident, as pointed out, that the fuses are not designed to protect the telephone apparatus, but are expected to reduce the fire hazard to the structure in which the telephone is placed, in case of a cross between the telephone circuit and the power circuit. In addition to being so proportioned that they will protect the house circuits from excessive currents, three other factors

are taken into account in fixing upon the size of fuses to be used:—

1—The fuses should have as large an instantaneous current carrying capacity as possible, to avoid excessive maintenance, due to the operation of the fuses by lightning.

2—Since the potential of a constant current arc lighting circuit may rise to high value when impedance is added—as, for example, when an attempt is made to open the circuit—it will be obvious that it will be very hazardous to interrupt the current in such a circuit. If the fuse should operate under these conditions, a dangerous arc would probably be maintained—thus introducing a rather serious fire hazard. To eliminate this possibility, sub-station fuses and protectors should be made with sufficient capacity to carry safely and continuously a current as large as that of the ordinary series arc lighting circuits, to which the telephone line is likely to be exposed.

3—As the telephone equipment may be surrounded by inflammable curtains, papers, etc., it is essential that the operation of the fuse shall not introduce a fire hazard. It therefore follows that practically no flash is allowable even when the fuse is operated under the most severe conditions of load and voltage, and a considerable study has been made of the shape of the shell, the disposition of the wire, the form and arrangement of packing material, the form and position of the vents and other considerations.

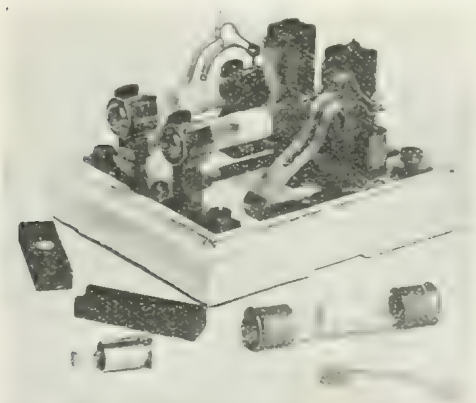


FIG. 5—PROTECTION EQUIPMENT AND MOUNTING FOR A MAGNETO SUBSCRIBER'S STATION

As commonly applied in Europe. Note glass tube fuses in contrast to fiber fuses used in America.

Turning now to Case *2*, the protection of magneto subscriber's stations—substantially the same apparatus is provided as in Case *1*, except that heat coils are employed in addition to cutouts and fuses. An example of a protector for this service is shown in Fig. 5, while the commonly employed circuit is shown in Fig. 6. As previously pointed out, the object of the heat coils is to prevent the passage of small currents (called sneak currents) through the telephone signaling apparatus for any considerable time. Sneak currents, which are not dangerous if continued for short intervals only, may result from a number of conditions—a very common cause being crosses with comparatively low-potential power circuits under such conditions that the cutout on the wire crossed does not discharge, while the cutout on the other wire of the same line does discharge. Such a condition, which may be caused by unequal separation in the cutouts, forces the current to pass through the telephone apparatus to ground.

Subscriber's stations which are exposed to constant-potential power circuits, whose voltages are above 5 000 volts or constant-current circuits above 7 500 volts, or 7.5 amperes, constitute extra hazardous exposures and each case should be considered individually. The telephone system used in connection with

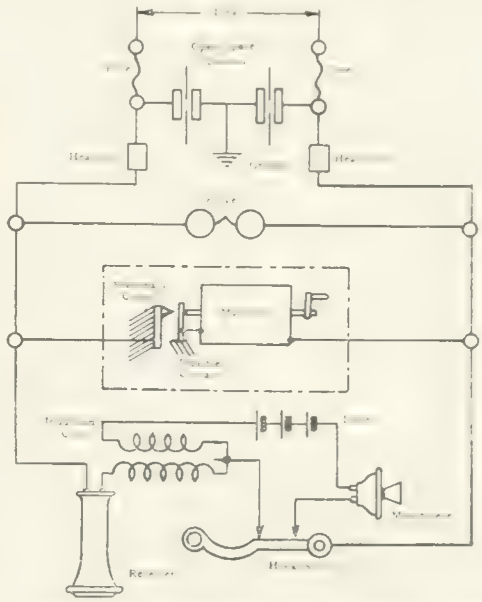


FIG. 6—DIAGRAM OF CONNECTIONS FOR MAGNETO STATION

Showing types of protective apparatus used.

a high-potential transmission line, is the most common example of this. Protection is usually best secured in these instances by the use of a special "insulating transformer," combined with fuses and cutouts. One common arrangement is that shown in Figs. 7 and 8.

In the case of telephone lines carried on the same towers as transmission lines, the danger of crossed wires as well as the magnitude of induced disturbances are much greater than normal and it is therefore desirable to provide both mechanical and electrical

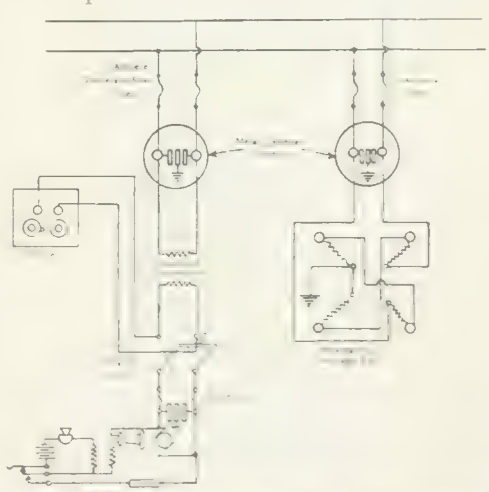


FIG. 7—DIAGRAM SHOWING SEPARATE FUSES IN THE PROTECTION OF TELEPHONE LINES FROM VERY HIGH VOLTAGE CIRCUITS

protection. Fig. 7 shows the electrical circuit which is most frequently employed, while Fig. 8 illustrates some of the mechanical precautions which are taken. It should be kept in mind that the potentials to which the telephone line may be exposed in the case under

discussion may be 50 000 volts or over, and therefore provision must be made for extinguishing arcs automatically and separating the telephone apparatus from the crossed circuit. In Fig. 8 the exposed line is illustrated on the left attached to special high tension insulators on pole *X*. At a distance of four feet from the pole the drop wires are connected and pass

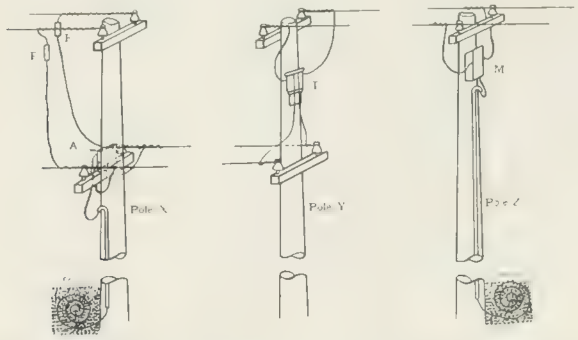


FIG. 8—SCHEMATIC ARRANGEMENT OF EQUIPMENT ON LINES NEAR HIGH TENSION TRANSMISSION SYSTEMS

F—Special drop wire fuses—one ampere rating.
A—Special lightning arrester.
T—Special 50 000 volt insulating transformer.
M—Open space cutout protector.
All insulators on poles X and Y are of the high-tension type.

through special fuses *F* and F_1 to high tension insulators on a second cross arm six feet below the incoming line. The fuses *F* and F_1 are of a special type mounted in porcelain shells and so designed that if an arc occurs when they are operated, they will break apart, thus allowing the drop wire to fall clear from the line. A special spark gap discharging at about 5 000 volts is mounted on this pole, as shown at *A* in Fig. 8. Special precaution should be taken to insure that the ground connection is surely made and

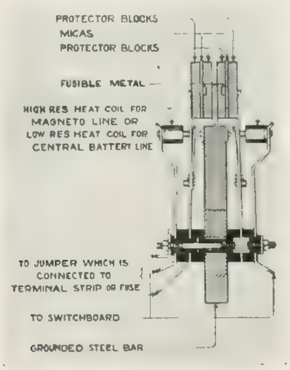


FIG. 9—DIAGRAMMATIC SKETCH OF PROTECTOR USED FOR AMERICAN TELEPHONE EXCHANGES

that the earth in which it is buried is permanently moist.

From pole *X* the leads pass to the lower crossarm of pole *Y* and then upward to the special insulating transformer *T*. The primary and secondary windings are insulated from each other and from the core sufficiently to stand a 50 000 volt test. The object of the transformer is to eliminate as far as possible all opportunity for high potential to reach the telephone set. The transformer is so designed that the loss in transmission through it is a minimum.

Passing upward from the secondary of the transformer the telephone leads are connected to high potential insulators and then are carried to pole *Z* on which is mounted the telephone set and associated apparatus shown in Fig. 7. In the case of telephone circuits which are subject to the continued induction of potentials of dangerous values, it is desirable to provide a "drainage" to ground. This is commercially accomplished by the arrangement in Fig. 7, which allows a direct or alternating current of low frequency to pass simultaneously from both wires to the ground

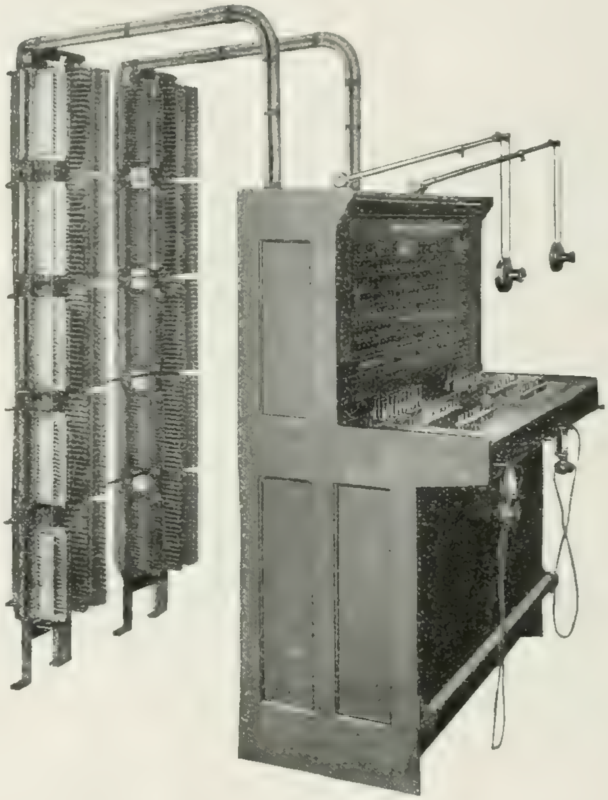


FIG. 10—TELEPHONE EXCHANGE BOARD AND ITS PROTECTIVE APPARATUS

with little impedance, but offers a considerable impedance to the high-frequency telephone currents, thus causing a minimum of transmission loss.

Central Office Protection (Telephone Exchanges)—In general, all central offices are considered to be exposed to both lightning and crosses with power circuits similar to those described under "Subscriber's Station Protection—Case *1*," and therefore the protection of central office equipment requires, in general, open spaced cutouts, heat coils and fuses. The usual cutout is the carbon block with fusible plug insert, while the seven-ampere fuses are commonly employed. Fig. 9 shows a general sketch of a central station protector of this type and a complete installation is shown in Fig. 10. For common battery exchanges, where a portion of the energy from the central storage battery

to the subscriber passes through the apparatus, the low-resistance heat coil is used, while for magneto offices (and this covers the usual circuits operated by power transmission and public utility companies), high-resistance heat coils are commonly employed. Heat coils are always located in the central office. Figs. 11 and 12 show typical central office protectors employed in Europe, while Fig. 13 is an example of American practice. The extreme compactness of the apparatus will be noticed in distinction to the ample spacing common with power apparatus.

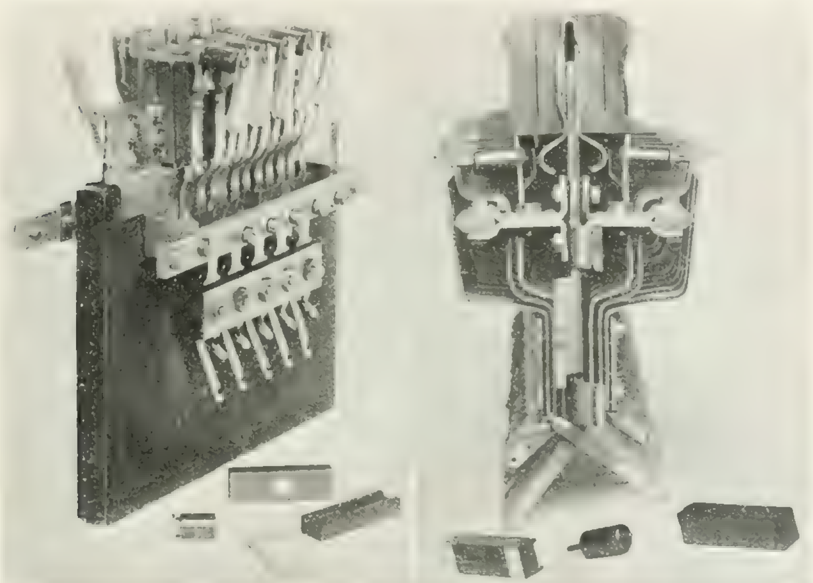


FIG. 11 AND 12—TYPES OF CENTRAL OFFICE PROTECTORS EMPLOYED IN EUROPE

If the telephone lines enter the central office as open wires, or as aerial cable, the fuses should be located in the central office, or in the cable terminal immediately adjacent to the central office. This is both for reasons of maintenance and protection. If the lines enter the central office as underground cable, the fuses should be located at the outer end of the underground cable—if such cable is extended by any exposed circuits. The distributing wire from the outer end of an underground cable is commonly considered unexposed when the underground cable extends continuously from the central office to another central office or to a building which it serves or to a block where the distribution is wholly by means of ring construction carried on walls or in fence cables, which are not exposed to lightning or power circuits. In all other cases, fuses are usually provided at the outer end of the underground cable.

Cable Protection—Underground, submarine and aerial cables can be most satisfactorily considered together, since they are very commonly interconnected; and also they may be considered as exposed to lightning and the type of hazards given in the first class.

At the junction of underground and aerial cables, seven-ampere fuses alone should be employed; while at the junction of open wire line and underground cable, seven-ampere fuses should always be provided, assuming that the underground cable is continuous from the junction point to the central office, as these fuses are essentially a part of the central office protection; also, in addition to the fuses, metal block, open space cutouts with 0.010 inch mica separators are commonly provided at the open wire end of the fuses on those open wire lines which are long enough to bring in trouble from lightning. Under average conditions, it has been found that open wire lines under one-half mile in length, bring in trouble from lightning disturbances so infrequently that special protection is not warranted.

At the junction of open wires and aerial cables, metal block open space cutouts with 0.010 inch separators should be installed where the lines are more than one-half mile in length; otherwise, no protection will be required.

From this rather brief summary it will be evident that the engineering, economic and legal sides of protection have been carefully developed. However, the problem is not a simple one as the enormous number of telephone sets multiplies the smallest item to large proportions. For this reason there are a number of problems still to be solved, such as the relatively high maintenance introduced by the short-circuiting of the carbon

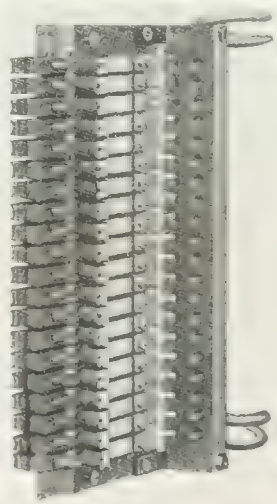


FIG. 13—AMERICAN TYPE OF CENTRAL OFFICE PROTECTOR

blocks and the operation of fuses and heat coils. One of the more recent lines of development, not yet entirely commercialized, is the substitution of a spark gap in a vacuum for the carbon blocks now employed.

Charleroi Sub-Station of the Pittsburgh Railways Company

G. C. Hecker
Chief Electrician,
Pittsburgh Railways Company

THE NEW sub-station of the Pittsburgh Railways Company at Charleroi, Pa., was designed both to meet the requirements of the interurban and local railway service and to furnish power for the operation of the equipment of the Carnegie Coal Company at Charleroi. Both of these loads have widely fluctuating characteristics and simultaneous occurrence of their peaks impose very heavy loads on the sub-station apparatus. In the design of the station, reliability of service was considered the most important factor.

The railway load consists of interurban passenger cars, operating on a half-hour schedule, interurban freight cars and numerous supply and maintenance of way cars. In addition special service is maintained, during the summer months, between Charleroi and other points on the Monongahela River and Eldora Park. The total connected load of the

FIG. 1—PORTABLE SUB-STATION IN USE AT CHARLEROI

Carnegie Coal Company is about 2 300 horse-power. This load consists of four 15 ton haulage locomotives, twelve six ton gathering locomotives, twenty continuous cutting mining machines, twelve electrically-operated pumps for the entries and rooms, and a number of motors ranging from 3 to 35 horse-power, for hoisting, screening, dumping and shifting. The 15 ton locomotives are each equipped with two 100 horse-power motors and are arranged for tandem operation. The six ton locomotives are each equipped with two 35 horse-power motors and one 7.5 horse-power motor operated crab reel.

Previous to the erection of the new sub-station the railway service was supplied from three 200 kw rotary converters and a 320 ampere-hour battery, the load of the latter being controlled by a differential booster. This station, which was located at McKean avenue and First street, was operated in parallel with the Riverview sub-station, about eight miles distant. With the addition of the Carnegie Coal Company load, it was evident that considerable additional capacity would be required at the Charleroi station. Enlargement of the station was not considered advisable for a number of reasons and it was decided to build a new station, install larger units, abandon the battery

FIG. 2—NEW CHARLEROI SUB-STATION

and use the old units for increasing the capacity of other stations having similar equipment.

To provide the necessary additional capacity during the erection of the new station, the portable substation of the railways company was installed at the Charleroi car barn, about one mile distant from the old station and several hundred feet from the proposed location of the new station. The portable substation is an all steel, double-truck car mounted on 24 inch wheels. In the cab, which covers approximately one-half of the car, is installed a 500 kw rotary converter with the necessary switchboard equip-

FIG. 3—INTERIOR OF SUB-STATION

ment. A 550 k.v.a., three-phase, oil-insulated, self-cooled, outdoor type transformer, provided with high-tension taps for voltages ranging from 10 000 to 22 000 volts, is mounted on the other end of the car. The high tension switches, fuses and lightning arresters, of the Burke horn-gap type, are mounted on the roof of the cab. Fig. 1 shows the portable sub-

station as it was installed at Charleroi. Connections were made with the direct-current feeders so that the portable station could be operated independently on a part of the load, or in parallel with either or both the Charleroi or Riverview stations. No trouble was experienced in handling the load during the erection of the new station.

BUILDING

The new sub-station building, located at McKean avenue and Thirteenth street, is 72 feet long by 42 feet wide and is practically fireproof. The foundation walls and piers for the floor supports are of concrete. The building walls are constructed of red, rock-faced, waterproof paving brick. All coping, sills, keys, etc., are of Cleveland sandstone. The reinforced concrete floor is supported on steel beams of sufficient size and strength to carry the equipment without any foundations other than the building walls and the concrete floor piers. The floor is finished with master builders' floor topping blocked out in four foot squares. The roof, which is of reinforced concrete, is supported on steel roof trusses and covered with three ply Warren Ehret slag roofing. A monitor ridge ventilator extends over one half of the building. On the main floor are a store room and toilet room. The station is piped for water and gas. The basement has an average height of about four and one-half feet and is provided with eight windows for ventilation. A fireproof oil house is built on the platform at the rear of the building.

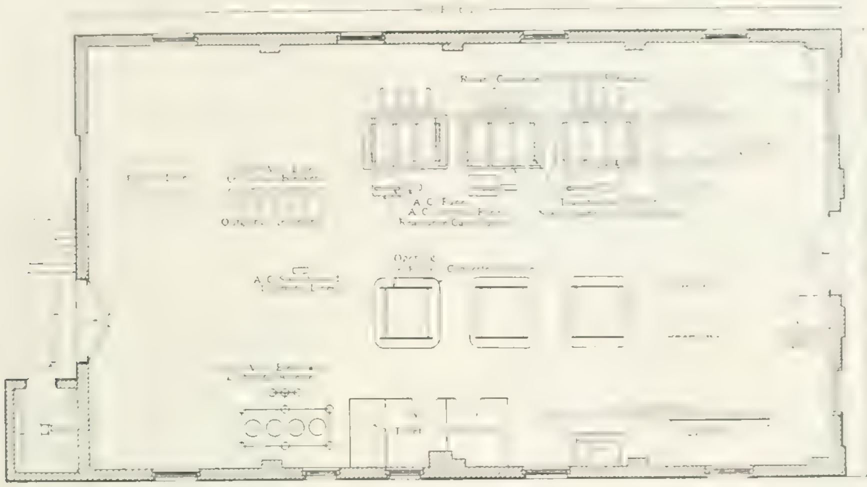


FIG. 4—FLOOR PLAN SHOWING ARRANGEMENT OF APPARATUS

EQUIPMENT

Provision is made for the installation of two incoming and two outgoing high-tension lines and four 500 kw rotary converters with the necessary transformers and switchboard equipment. The present equipment consists of one incoming 22 000 volt line, three 500 kw, six-phase, 60 cycle, 600 volt rotary converters, three 22 000/424 volt, three-phase, 60 cycle, oil-insulated, self-cooled transformers and the necessary switchboards, oil circuit breakers, lightning arresters and other auxiliary apparatus. The incoming high-tension line enters the building through combination wall or roof insulators and is connected directly to a three-phase, electrolytic lightning arrester, as shown in Figs. 5 and 6. Connection is made above the lightning arrester, through choke coils, disconnecting switches and an oil circuit breaker to the station bus. The method of supporting the choke coils, as shown in Fig. 7, is simple and requires a minimum of supporting structure. The

FIG. 5—INCOMING 22 000 VOLT LINE

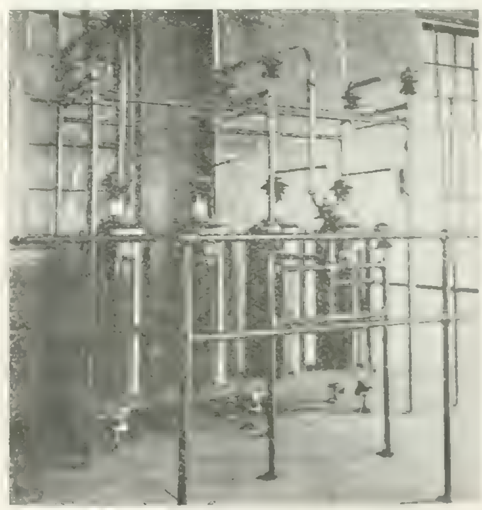


FIG. 6—THREE-PHASE, 22 000 VOLT ELECTROLYTIC LIGHTNING ARRESTERS

high-tension wiring is supported on insulators mounted on a pipe structure. The present line structure, shown in Fig. 8, will accommodate one outgoing line in addition to the present incoming line. This structure will be duplicated when the second incoming and outgoing lines are required. The outgoing lines will be

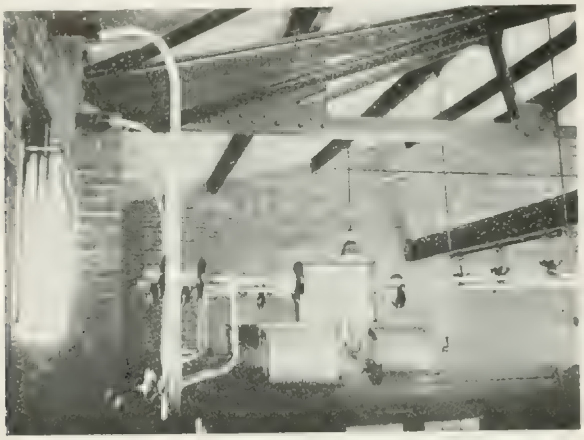


FIG. 7—METHOD OF SUPPORTING CHOKE COILS IN 22 000 VOLT LINES

taken out through the roof, cross over the building, and leave by the same route as the incoming lines.

The station high-tension bus is installed at the rear of the transformers and connection is made to the latter through disconnecting switches and oil circuit breakers. Series transformers are provided in the station bus for the operation of the station wattmeter, and in the line and transformer leads for the operation of the trip coils and instruments. The three-pole, 300 ampere, 35 000 volt, remote mechanically-op-

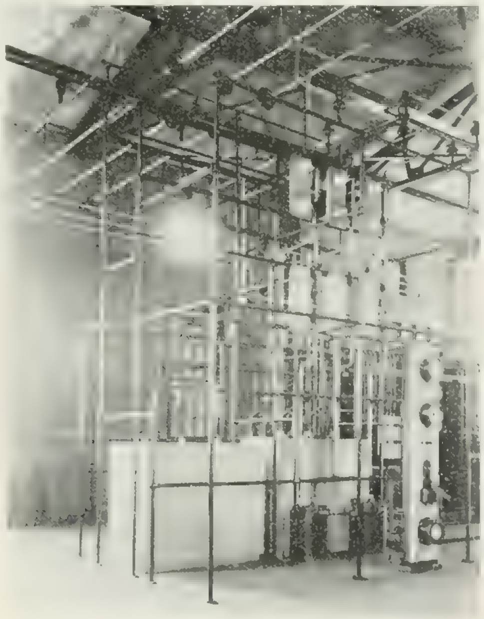


FIG. 8—22 000 VOLT LINE STRUCTURE

erated, automatic oil circuit breakers are mounted in concrete cells. All operating rods and bell cranks are installed in the basement and supported from the floor structure.

The transformers are installed on a steel framework directly over openings in the floor, this method of installation giving a free circulation of air on all sides of the transformers. The high-tension windings are provided with the usual number of taps with full-load ratings and in addition are provided with 15 000 volt reduced capacity taps, as the line is now being operated at this voltage. Ninety-one percent taps are brought out on the low-tension windings, in addition to the thirty-seven percent starting taps, and are connected through a double-throw switch so that the converter voltage may be reduced nine percent. This permits lowering the trolley voltage, which after midnight rises to about 640 volts due to the rise in high-tension voltage after the shutting down of other stations operated on this line. The direct-current circuit breakers, of course, must be opened when changing from one voltage to the other, if all machines are in operation. However, if a spare machine is available (as is usually the case after midnight), the change can be effected without an interruption. For example, if one machine is operating on the 100 percent taps and it is desired to reduce the voltage, a second ma-

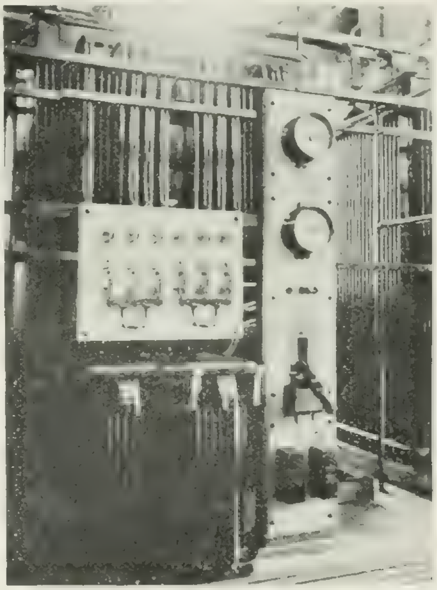


FIG. 9—ALTERNATING-CURRENT ROTARY CONVERTER PANEL AND STARTING PANEL

chine is cut in on the 91 percent taps. The field rheostats of both machines are adjusted, the machines are paralleled on the direct-current side and the circuit breaker of the machine running on the 100 percent taps is opened. The voltage on the machine carrying the load is then adjusted to the proper value and the other machine is shut down.

The rotary converters are of the alternating-current, self-starting type and are installed directly over openings in the floor, thus obtaining very good ventilation and permitting of an excellent arrangement of the cables and connections. The field break-up switches are mounted on the frames of the machines just above the negative panels. On each negative panel are mounted, in the following order from left to right, the equalizer switch, the series field short-circuiting switch and the negative switch. The series field short-circuiting switch, when closed, provides a very low resistance connection around the series field of the converter

and is connected so that when starting from the direct-current side, the negative armature terminal is connected directly to the negative bus, and the series field circuit is opened. It is often desirable to operate the machines with these switches closed. For example, the station is frequently operated in parallel with a nearby station of another company, using motor-generator sets, and it has been found that the parallel

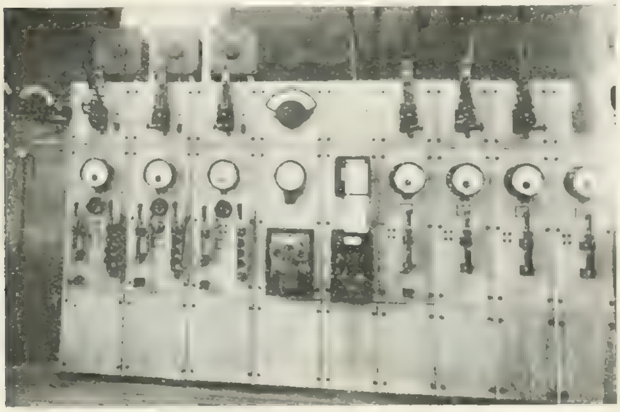


FIG. 10—DIRECT-CURRENT SWITCHBOARD

operation of the stations is much more satisfactory when the series fields of the rotary converters are short-circuited. It is not necessary to remove the load from the converters when making this change in connections. The machines are equipped with mechanical oscillators and overspeed devices, the latter operating the direct-current circuit breakers by means of low-voltage trip coils. External reactances for compounding are provided to compensate for high-tension line drop. All connections and wiring to the rotary converters are installed in the basement, the negative and equalizer busses being directly under the machines.

The switchboard is of blue Vermont marble. On the alternating-current line panel, Fig. 8, are mounted a line voltmeter, ammeter, ammeter receptacles, station alternating-current wattmeter and oil circuit breaker handle. On the rear of this panel are mounted the inverse time limit relays for the oil circuit breaker. Fig. 9 shows a front view of the alternating-current rotary converter panel and starting panel. On each converter panel are mounted an ammeter, ammeter receptacles, power-factor meter, inverse time limit relays and oil circuit breaker handle. The machine oil circuit breakers are provided with low voltage relays, operated from the bus potential transformers, and are electrically interlocked with the direct-current machine circuit breakers, so that both circuit breakers are automatically opened when the high-tension power supply is cut off. All series transformer leads are brought to terminal boards on the rear of the alternating-current panels, so arranged that the transformers may be short-circuited and the instrument circuits opened for testing or for other purposes. On each alternating-current starting panel are mounted two double-throw switches. The switch on the right (Fig. 9) is the starting switch and that on the left is the one used to change from the 100 to the 91 percent transformer taps as previously described.

The direct-current switchboard consists of the converter panels, station load panel, instrument and feeder panels for the Carnegie Coal Company and the railway feeder panels. Provision is made for extension of the switchboard to accommodate an additional converter and additional feeders. Figs. 10 and 11 show front and rear views of this switchboard. The field rheostats are mounted on the tie rods above the switchboard and their face plates are in plain view of the operator. The starting grids are mounted at the rear of the switchboard and are thoroughly insulated. A double bus is provided so that any converter may be operated independently on the coal company's load if desired. The railway feeders, however, are connected to the upper bus only. The lower bus can be extended at any time and the railway feeders connected to it, which would involve changing the feeder switches from single to double- throw and rearranging the connections on the rear of the panels. On the instrument panel of the coal company feeder are mounted a Thompson watt-hour meter and a curve drawing watt-meter, the latter being used to determine the "demand charge" which is based on a two minute peak. An electrolytic lightning arrester is installed

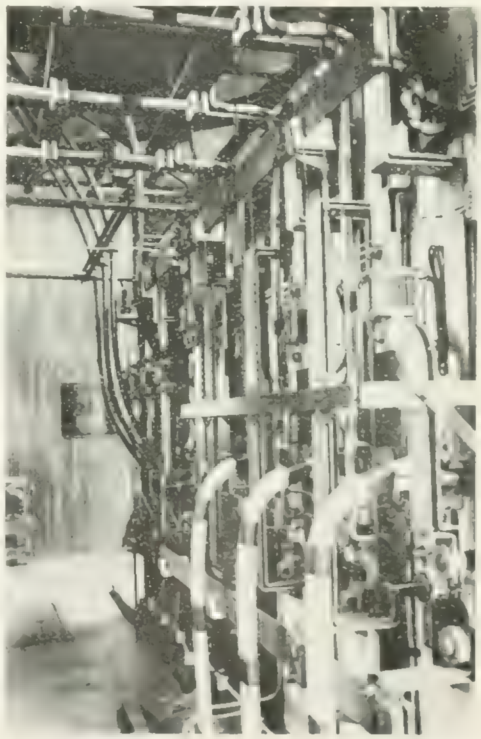


FIG. 11—REAR OF DIRECT-CURRENT SWITCHBOARD

on the railway bus and individual magnetic blow-out arresters on the feeders. All lightning arrester ground wires are run as directly as possible to the ground connections, which consist of a number of three-quarter inch pipes, eight feet long and a 1/4 by 48 by 48 inch copper plate. The pipes are connected to the copper plate and connection is made from the latter to the negative bus, through a grid resistor. The

latter connection is provided to insure proper operation of the magnetic blowout arresters. The use of a suitable resistance in the connection between the ground plate and the negative bus practically eliminates stray return currents without affecting the operation of the arresters.

The cables from the converter are brought to the switchboard through an opening or cable way in the floor. This opening is capped with two-inch slate panels cut and drilled to receive the cables and is elevated about two inches above the floor level to better protect the cables at this point. The negative and equalizer connections are brought through the floor at the machine in the same manner.

GENERAL

A 12 inch I-beam extending the length of the building and supported from the roof trusses, carries a five ton trolley from which a chain hoist may be suspended for dismantling and assembling machines. An air compressor, governor, tank and hose for blowing out the machines is a part of the auxiliary equipment.

The general lighting of the station is carried out by means of 250 watt tungsten lamps equipped with enameled metal reflectors. The arrangement of these lamps is such that a very uniform distribution of light is obtained, and the use of lamps on the switchboard is eliminated, except in the case of the illuminated dial station instruments. A number of receptacles are located at convenient points for attaching an extension cord with lamp.

The station has been in operation several months. Practically the only trouble experienced was the opening of the oil circuit breakers on overload, due to the increased high-tension current resulting from operation at 15 000 volts. This was overcome by the use of additional weights on the relays and will no doubt be eliminated when the high-tension voltage is raised to 22 000. The railway load and the coal company load are carried on the same bus in order to take advantage of the diversity factor of the two loads. When the load of the coal company becomes heavy enough to justify the use of one machine exclusively, their service can be supplied from a separate bus. The cost of the present installation, including building, real estate, equipment and erection, is $27.80 per kilowatt. With the installation of the fourth machine the complete cost of the station will be approximately $26.00 per kilowatt.

Electro-Percussive Welding*

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THE SOLDERING and welding of aluminum has always given trouble, and the satisfactory joining of small wires has been very difficult if not impossible. In the last few years, the substitution of aluminum wire for copper wire has demanded a good means of joining aluminum and the electro-percussive method of welding was developed primarily for this purpose after a very thorough investigation into the available methods of soldering and welding of aluminum. Several other special applications of the method are now made and the future field of application seems sufficiently promising to justify a description of this new process, which will weld practically any two metals, whether alike or different, of high or low melting point, or of unequal thermal conductance. With aluminum the natural oxide, which always covers the surfaces of the two pieces to be welded, prevents the metal from flowing together after the ends have been melted in the usual way. Large wires and rods of aluminum can be welded by melting the metal under the oxide film and then suddenly pushing the ends of the two pieces together. This breaks the oxide films, allows the clean metal to flow together and at the same ime wash away the broken pieces of oxide in a surplus of molten metal. Small wires cannot be joined satisfactorily by this method, or in air by any other prolonged heating method.

DURING the year 1905, while experimenting with electrolytic condensers and rectifiers, one of the authors noticed that wires could be connected to the aluminum plates by the condenser spark when the cells were discharged. It was noticed that copper wires could be attached to aluminum or that two pieces of aluminum could be joined together by the condenser spark. This was of course only a feeble welding of the metals for temporary connections. But later on, while working with aluminum wire, the demand for a welding method and a careful theoretical consideration of what happened in the early tests with electrolytic condensers made it appear worth while to try out the method of welding with a condenser discharge on a larger scale.

From the first, the same principle of a simultaneous condenser discharge and percussive engagement has been used, but during the tests and development of welding tools it was found that the best results depend upon several variables, such as the condenser capacitance, the velocity and force of impact, the voltage, and the resistance and inductance in circuit. The first apparatus consisted of two hinged arms with wire grips in their ends. Wires placed in the grips were connected to the terminals of a charged electrolytic condenser. These arms, upon release, were drawn together and, at the instant of contact, the explosive condenser discharge and the forge would weld the ends together. This apparatus was not very satisfactory as it did not allow separate study

*Revised by the authors from a paper read at the annual convention of the American Electrochemical Society at Niagara Falls, October 1-3, 1914.

of the effect of variation of velocity, momentum, kinetic energy, etc. So a second apparatus was built similar to a pile driver, with one stationary and one one moving wire grip. With this arrangement the forge and velocity could be varied independently by the separate adjustment of the drop and mass of the

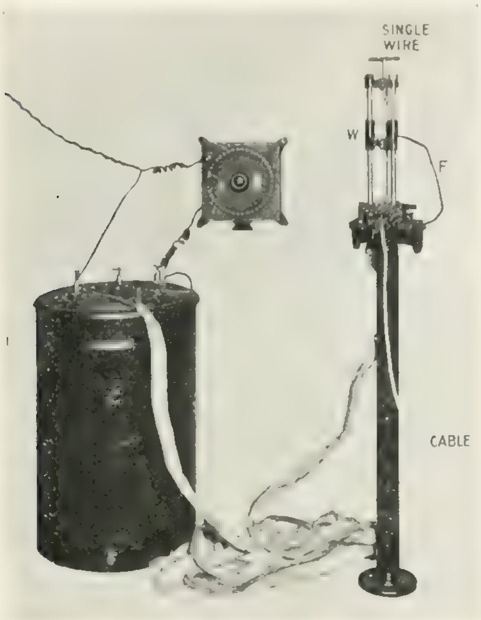


FIG. I—PERCUSSIVE WELDING OUTFIT
F—Flexible connection to top.
W—Forging weight.
R—Rheostat.
C—Electrolytic condenser.

moving part. Other welding tools have been designed in which springs have been used to shoot the wire grips together horizontally; however, these have not been as satisfactory as the gravitational type.

PROCESS OF WELDING

A portable tool of the gravitational type set to attach a copper lead wire to a coil of aluminum wire is shown in Fig. 2. The welding circuit, Fig. 3, consists of a generator G which charges an electrolytic condenser C through a high resistance R. Adjustment of the voltage of the charged condenser is obtained by field control of the generator or by varying the resistors R and R'. The wires WW to be welded are secured in the wire grips of the welding tool which are connected to the terminals of the condenser through an inductance L of from 2 to 10 turns of cable. A spring switch S with carbon contacts, normally held closed is connected across the jaws of the welder so that their potential difference will be zero while the wires are being put in or the finished product is being removed. The welder is connected to the auxiliary apparatus by means of long flexible cables which allow welding within a radius of about 50 feet without moving the condenser and other heavy apparatus.

The process of welding is as follows:—The wires are secured in the wire grips and the ends cut off as short as possible with a suitable pair of cutters. The switch S is then opened thus *charging* the condenser to the proper voltage. A catch is then released which lets the sliding member fall and bring the ends of the two wires into percussive engagement. At the instant of contact, the short-circuit current of the condenser builds up to such a value that the ends of the wire are melted by the explosive discharge and instantly forged together by the blow of the falling mass. The weld is then complete and after being removed from the machine will be found to have the strength of the original wire.

The generation of the heat is so localized, so sudden and so intense, that there is no time for unequal heat conduction through the shanks of the wire and the ends will be melted and even vaporized whether the melting point is high or low. For this reason metals of different kinds can be welded together independent of their electrical resistance, melting point or heat conductance. Any combination of metals which has ever been tried will weld together, but the joints will not be permanent with such combinations as aluminum and tin, or lead and iron.

The generation of heat at the point of contact depends upon having an appreciable resistance offered to the current between the wire ends, and it is therefore necessary to cut the ends of the wires in such a way that they will make a point contact, preferably at the

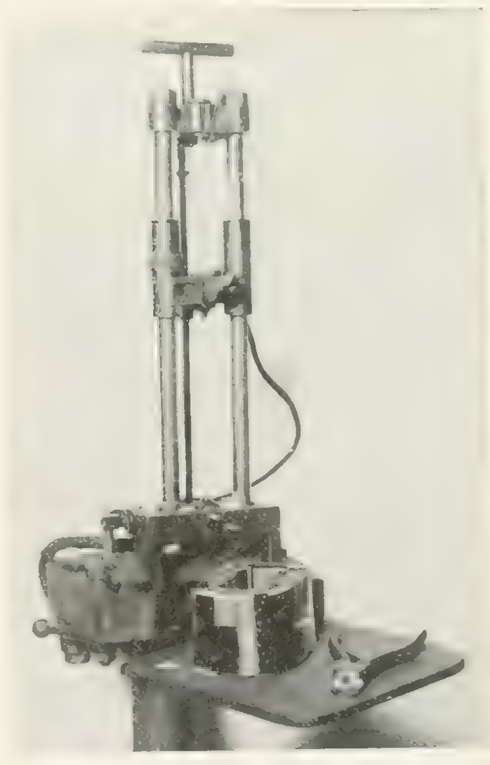


FIG. 2—GRAVITATIONAL TYPE WELDING TOOL

center, so that the energy of the condenser will vaporize the small section of metal and melt the rapidly approaching surfaces with the intense heat of the arc. To do this the wires are cut with ordinary cutters which give a chisel edge. The two wires are cut off in such a way that the two chisel edges are at right

angles and the point of first contact will be at the intersection at the center.

The time between the first contact and the finished weld is of such short duration that the exact action cannot be recorded but is supposed to be about as shown in Fig. 4. In *a* the wires are approaching at a velocity of from 65 to 200 cm. per sec.; *b* shows

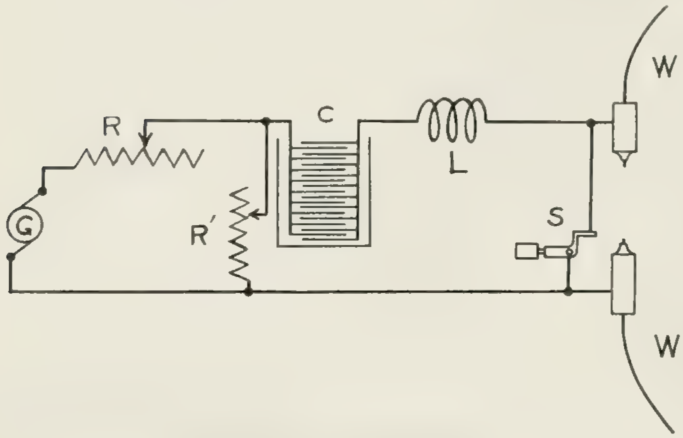


FIG. 3—DIAGRAM OF CONNECTIONS

the first contact at which time the current begins to build up and heat the small section of metal carrying the current; *c* shows the wire ends again separated, not by appreciably retarding or reversing the motion of the upper wire but by melting and vaporizing the metal which first touched together; *d* shows the wire chucks closer together but the arc still burning between the wires. At *e* the second contact has been made, the arc extinguished and the forge of the metal has begun; and *f* shows the completed weld after the upper chuck has come to rest and the forge is complete.

The curves, Fig. 5, drawn to scale, show the current through and the voltage across the weld during the operation of welding a No. 18 B & S gauge wire. These curves were taken directly from an oscillogram, and the power or product curve has been figured and drawn in. Electrically the weld is complete in 0.0012 second and although 23 kilowatts are being dissipated between the ends of the wire at a certain instant, the total energy used at the weld is only 0.00000123 kilowatt-hour or enough to light an ordinary 50 watt, 16 candle power lamp for 0.09 second. The cost of this amount of energy at 10 cents

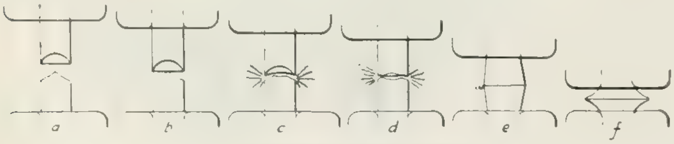


FIG. 4—STAGES OF THE WELD

per kilowatt-hour would be 12 millionths of a cent. The letters *a, b, c, d, e, f,* have been placed along the the time of axis of Fig. 5 to indicate the time corresponding to the various views in Fig. 4. It will be noticed that the watt curve is oscillatory and that the negative values would indicate a return of stored energy. Such a thing would be impossible from a metallic arc but can be explained by saying that the voltage was measured above and below instead of between the wire chucks, and the storage and return of energy is from the magnetic flux produced in the steel chucks set up by the current of 500 amperes flowing through them.

The electrolytic condenser has high absorption if the current through it is reversed in an attempt to change its polarity. For this reason any tendency toward an oscillatory discharge will be quickly damped by the internal losses of the condenser and the energy of the charge will be partly lost. With an ordinary circuit, enough resistance cannot be maintained at the weld to prolong the current and heating until the final contact, and the very high frequency oscillation due to the small inductance of the circuit will cause an explosive snap at the weld, the current will suddenly be damped by the absorption of the condenser, the arc will go out before

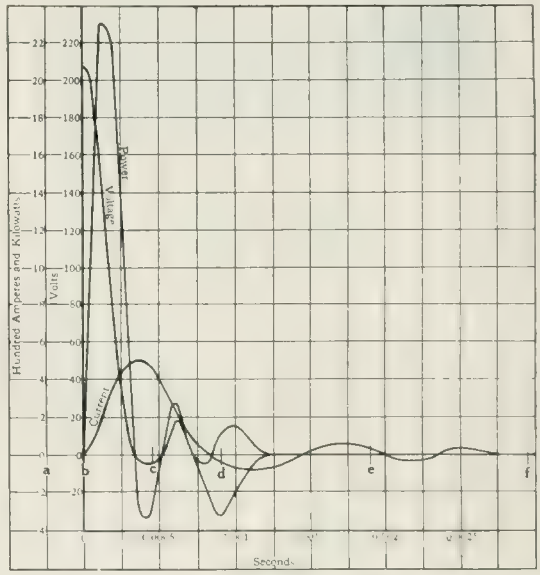


FIG. 5—OSCILLOGRAM OF CURRENT AND VOLTAGE IN WELDING CIRCUIT

The letters *a* to *f* correspond to the stages of the weld shown in Fig. 4.

final contact, and the wires will not be hot enough to form a good weld. In order to maintain the arc until final contact it is, therefore, necessary to lower the frequency of the discharge and prevent the sudden rise of current at the first instant of contact by inserting additional inductance in the discharge circuit. This inductance prevents the explosive and wasteful discharge, prolongs the current, and apparently maintains the heating until final contact is effected. The inductance will of course increase the tendency toward oscillation and although the total energy dissipated at the weld may be diminished, it is more efficiently used and not wasted in noise or thrown out in metallic vapor.

The equations expressing this interesting transient are not as valuable as the ear in telling what adjust-

ments are best for any particular weld. The mass and drop of the falling chuck must be sufficient to forge the wire slightly and then all that is necessary is to adjust the voltage and inductance so that the discharge sounds like a splash or thud instead of a sharp crack. Generally the operator can estimate the settings and no trials need be made. When the same kind of work is to be repeated, the machine once set

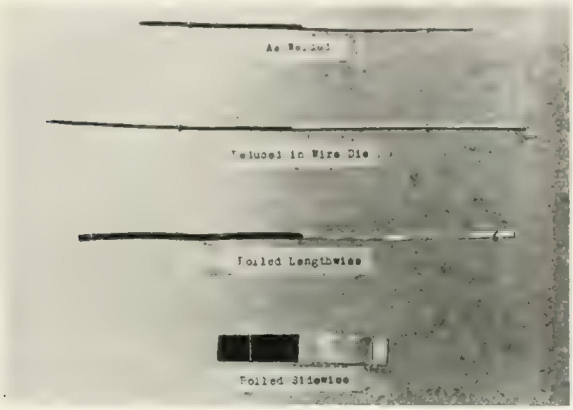


FIG. 6—SAMPLES OF WELDS BETWEEN ALUMINUM AND COPPER
Showing ductility and malleability of the weld.

will make a perfect weld every time, and the rate of welding will be limited only by the mechanical handling of the product.

The new process has some distinct advantages over the usual methods of working metals and is especially adapted to welding small sections of like or unlike metals. In many cases a saving of expensive material can be effected, in other cases work can be done which cannot be done by other methods; joints can be made without overheating the metals, and the welds will be ductile and strong.

PROPERTIES OF THE WELD

Many of the alloys of most metals are very hard and brittle. As an example there are alloys near both ends of the copper-aluminum series which are unworkable, and yet electro-percussive welds between these two metals are so ductile that they may be worked in a die, forged or rolled into thin foil. Any alloy formed at the weld must range from 100 percent copper on one side to 100 percent aluminum on the other; but possibly the brittle combinations are so thin that the joint

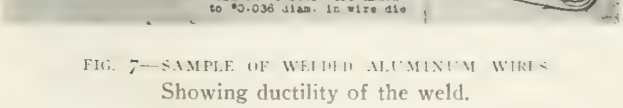


FIG. 7—SAMPLE OF WELDED ALUMINUM WIRES
Showing ductility of the weld.

as a whole is flexible and ductile. This joint between aluminum and copper is of great importance, as copper lead wires, which solder and connect easily, can readily be attached to aluminum coils. At first it was feared that a diffusion of the two metals in service would finally result in a brittle joint, but tests show that after four years the joints are practically as strong and ductile as when first made. Similar ductility has been noted in almost every combination of metals when first welded, but diffusion, disintegration and loss of ductility eventually result in such welds as silver to tin, or aluminum to tin.

Metals which are either hardened or softened with heating and sudden cooling can be welded together without appreciable change in the physical properties of the material. Tempered spring steel welded, reduced to uniform diameter, and tested has shown equal or greater strength at and near the weld without any noticable change in temper. Metals such as hard drawn copper, silver, aluminum, etc., which soften with heat can be welded together without causing any local annealing, and these metals and steel, when soft, can be welded together without detrimental local hardening.

Several possible explanations of the constancy of the mechanical properties before and after welding can be given. First, such sudden heating and cooling may not allow change in molecular structure.

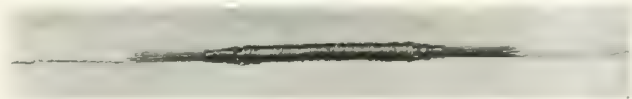


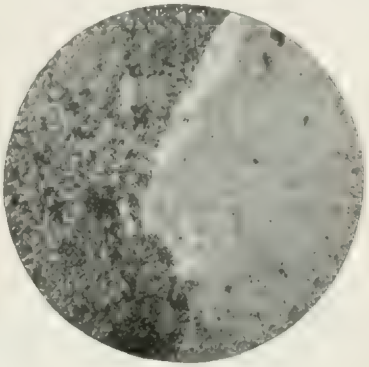
FIG. 8—METHOD OF SPLICING ALUMINUM CABLES

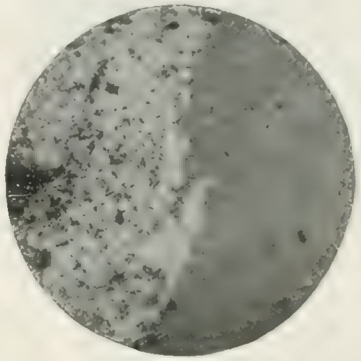
By welding a short length of copper wire to each of the strands of the cable, and then twisting or wrapping and soldering the copper ends. After the joint is soldered, an aluminum tube will be placed over the joints to prevent any electric action between the copper and the aluminum.

Second, with hard steel, the heated metal at the weld is so suddenly cooled by conduction of heat into the two shanks of metal that it is again hardened. Third, with hard copper, silver, aluminum, etc., the heating and sudden cooling would ordinarily soften the metal, but the cold forge of the blow in welding possibly hardens it again. Fourth, the metal subjected to the sudden heat cycle may be hardened or annealed (depending upon the characteristics of the material welded), but the amount of material affected may be too small to be detected. As an example, in welding No. 18 hard drawn aluminum wire, 0.00123 watt-hour or 1.06 small calories are dissipated at the weld. Assuming that none of the energy is lost in noise, radiant heat or metallic vapor and that one-half of the total is propagated in a heat wave in each direction along the wire, it can be shown mathematically that an annealing temperature will not be reached more than 0.05 mm. from the weld. The total amount of metal softened would then be a cylinder 0.1 mm. long and 1.02 mm. in diameter. A soft insertion of such proportions could hardly be detected.

In welds between some metals diffusion takes place, but in any of the useful combinations the change is too slight to affect the ductility of the weld.

The welds as a rule show only a sharp dividing line between the metals but there is often an intermingling of the two at or near the center for a very short distance. Figs. 9 and 10 show a new weld and a three year old weld between aluminum and copper. The micrographs were taken at the irregular point in the weld. Elsewhere the line of divison is sharp and rather straight. In addition to the small irregularity of the dividing line some spots of bright material, possibly aluminum-copper alloy, are present at this point, but do not appear at other points in the weld. Both of these welds are so malleable that they are capable of being rolled into thin foil. Such welds, run at a temperature over 100 degrees C. by the passage of heavy direct current, failed to show sufficient diffusion to affect their mechanical properties. The heating current was maintained for weeks and tests were made with both directions of current flow. At higher temperatures (red heat) there was a very rapid diffusion of the metals and in a few minutes the metals were diffused for a distance of two or three inches.





FIGS. 9 AND 10—MICROGRAPHS OF ALUMINUM—COPPER WELDS × 1000

This type of weld offers a very convenient specimen for the study of the diffusion of different metals at different temperatures and under various other conditions. The micrograph of Figs. 11 and 12 show copper-plantinum and copper-silver respectively. Both of these welds show a sharp dividing line at 1 000 diameters and the weld of Fig. 11 is three years old.

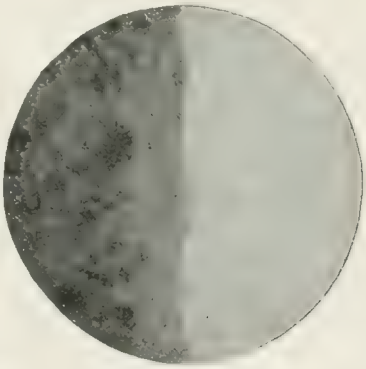


FIG. 11—MICROGRAPH OF COPPER—PLATINUM WELD × 1000

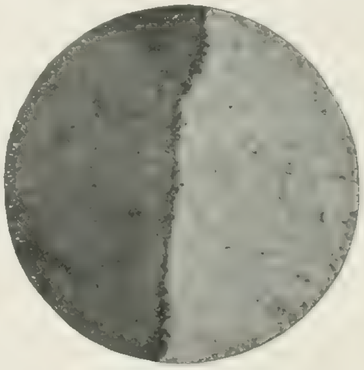


FIG. 12—MICROGRAPH OF COPPER—SILVER WELD × 1000

It is evident that the electrical resistance of two wires welded together will not be appreciably increased by the small film of high resistance alloy which may be formed in welding. Tests of a wire of 85 alternate pieces of aluminum and copper joined with 84 welds in a total length of 23.5 cms. showed an increase of 0.56 percent in resistance in three years. This test was made to determine whether or not diffusion would occur. The increase is small and may be due to a change in the joints or may be due to error of observation or oxidation of the wire. The sample was recently rolled and its malleability indicated no appreciable change.

APPLICATIONS

While the development of this welding method was brought about primarily by the necessity for the successful joining of aluminum wires and the joining of copper leads to such aluminum wires, it is evident that the method is capable of an extremely varied application. Since metals varying as widely in characteristics as platinum and tin may easily be welded, it follows that almost any metals may be joined where the joint is within the limits of the capacity of the welding apparatus. While the apparatus up to this time has been made only for welding wires 0.072 inch diameter and smaller, the application to larger sizes is merely a question of the design of suitable apparatus. Enough has also been done to show that welding of wires may be successfully accomplished; as for example, the welding of points to plates and small pieces to irregular shaped objects or flat surfaces. Electro-percussive welding has already been used to a considerable extent in the joining of aluminum wires; the welding of copper and aluminum wire; platinum and nickel; platinum and copper; and the welding of various types of thermocouple wires. It has also been used for the reclamation of short pieces of wires of various kinds, such as aluminum, platinum, spring steel, etc.

The electro-percussive method is also suitable for many applications in the jewelry trade, such as the joining of platinum without showing any solder line; the welding of sterling tips to table forks without annealing; the welding of pins to badges, and many other similar applications. The attachment of contact points of platinum, tungsten, silver, etc., for various electrical purposes is also very readily accomplished. The electro-percussive method of welding opens up a wide field of welding hitherto impossible. It also overlaps, to a certain extent, some of the present methods, but it will probably never supersede the existing methods for the welding of very large sections.

Considerations in the Design of Railway Motors

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(Continued from October issue)

BEARING HOUSINGS

THE design of the bearing housings for oil and waste lubrication which has been almost universally adopted since its introduction involves a number of detail features which have to be watched closely. It is usually possible to make the housings rugged enough by the use of either malleable iron or steel castings without going to excessive weights. The provision of sufficient capacity of oil well as well as a sufficiently large hole for feeding in the waste, often affords considerable difficulty, especially in case of motors for very small wheel diameters, on account of the small motor diameter. Similar difficulties often prevail in motors with large ratings on account of space limitations. In the latter case, it is also very difficult as a rule to make the openings for feeding

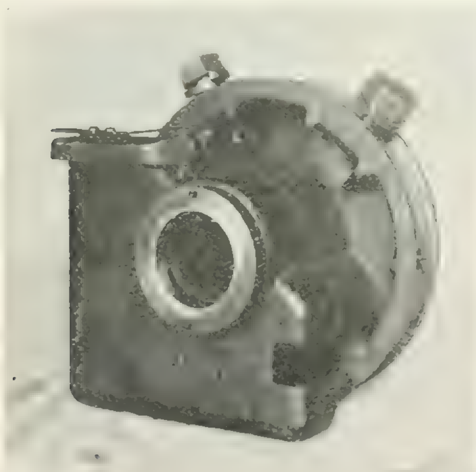


FIG. 6—NEW THROUGH BOLT TYPE OF ARMATURE HOUSING

the oil and waste accessible, especially in such cases where the design of the brake rigging is made without giving due consideration to the accessibility of the housing opening. Another point considered in the housing design is the particular shape of the walls supporting the waste so as to secure a good contact between the waste and the shaft, permitting at the same time the proper feeding of the oil through the waste. It is further necessary to provide a separate gauging opening for the oil and sufficiently large openings between these and the oil reservoir to permit free passage of oil even with a certain amount of collection of dirt at the bottom near the connecting opening.

It has already been intimated previously that certain difficulties are experienced in securely holding the armature housing to the upper half of the split motor frame. Of the various construction, that with two bolts going through the frame flange in the housing, have so far given the best results. As with all other constructions, a certain amount of inspection is required, especially with regard to keeping the two bolts tight. A frequent tightening of these bolts will naturally cause a certain wear of the thread on the bolts as well as on the housing. In the case of the housing this is rather objectionable because it means at times re-tapping for a larger bolt and consequent lack of interchangeability. In order to obviate this condition, the construction shown in Fig. 6 has recently been worked out; while maintaining the advantages of the previous method its disadvantages have been eliminated through the introduction of through bolts tapping into nuts located in recesses of the housing. In this case a worn thread does not cause much expense because the bolts as well as the nut can easily be replaced. The oil well openings should of course be provided with covers, which are held closed by heavy stiff springs during operation, permitting at the same time a locking of the covers in an open position, while the bearings are being packed and oiled. The covers are to be made tight by the use of felt lining or the like. In addition, they should be provided with deep overhanging skirts as a further safeguard against dirt.

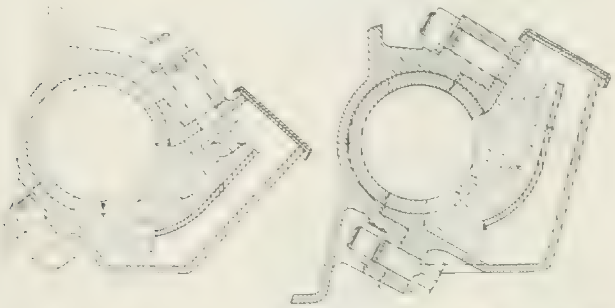
AXLE CAPS

In many considerations, the design of motor axle caps are much the same as in the case of motor housings, especially with regard to the oiling system. In addition it is desirable to have the bolts holding the axle caps in the frame through bolts. Due to the space limitations it is, however, especially with the lower bolts, often impracticable to furnish a real through bolt, that is, a bolt which can freely be removed in case of breakage. The best substitute possible in most such cases is a bolt which screws into a nut which in turn is located in a recess of the frame. In case of a breakage it is in this case at times necessary to chisel the bolt as is evident from Fig. 8, assuming, for instance, that the bolt breaks in the middle between the head and the nut. Nevertheless, such a bolt is slightly superior to a straight tap bolt which, in case of breakage, has to be drilled out and with which re-tapping is necessary in case the tap in the frame wears out. It is, however, again on account of space limitations, not always practical to avoid tap bolts altogether, without adding materially to the

weight of the motor. It is, therefore, considered too often to be the best compromise to get as many through bolts as possible without materially adding to the weight and to have one, sometimes two, tap bolts per axle cap. The final decision depends somewhat on the service conditions. With certain small light weight motors, the breakage of axle cap bolts is not very large, as a rule, and therefore the use of all through bolts is not so very essential, while in other cases such breakage is rather frequent and it becomes more important to have through bolts.

These remarks apply principally to box type motors; with split frame motors it is usually not very difficult to design for all through bolts, if the motor is split near the horizontal line as shown in Fig. 12.

The breakage of axle cap bolts may, of course, be reduced by designing the motor so that the bolts are not subjected to severe stresses. Among other things it is desirable to arrange the split of the axle cap so that the bolts do not have to carry any of the motor weight. With motors, which are split near the horizontal line, this can be accomplished rather easily as a rule because there the split of the axle bearing may be readily made horizontal as shown in Fig. 10. A similar arrangement usually leads to rather bad complications in connection with box type motors as well as with split motors which are split under an angle of about 45 degrees. There it is, as a rule, either necessary or at least more practical, to have the split nearer the vertical than to the horizontal. With the usual construction of axle caps for box type motors, a large inclination of the split line leads to a bad arrangement of the oiling system as will be seen from Fig. 7. This figure shows that as a consequence of the large inclination of the split, the oil window has to be shifted down and the position of the waste is such that it drops away from the window on account of its own weight which in turn, may make the oiling system inoperative and cause trouble in the axle bearings. Fig. 8 shows how this condition is avoided in modern motors, with the usual angle of split. It might further be mentioned that a large inclination of the split makes it more difficult to use through bolts for the lower axle cap bolts, as demonstrated in Figs. 7 and 8.



FIGS. 7 AND 8—SKETCHES SHOWING BAD AND GOOD ARRANGEMENTS OF OIL AND WASTE LUBRICATION IN AXLE BEARINGS

BEARINGS

One point deserving serious consideration in bearing design is to provide proper means for preventing the oil from getting into the motor. This can be accomplished by the proper combination of oil throwers and oil catching grooves in the bearing and housing, as well as holes and channels guiding the oil outside of the motor, where it may either be dropped on the ground or caught in a pocket provided for that purpose.

With the armature bearings, as well as the axle bearings, much attention has to be given to a design which permits an easy removal of the bearings providing at the same time secure means for preventing the bearings from shifting or turning. Due to the vibration and pounding of railway motors, this is not very easily accomplished and some trouble has been experienced in the past with the wearing out of both keys and dowel pins, as well as other more or less complicated substitutes. In some of the more up-to-date constructions, however, a detail study of the pressing and clamp fit of the bearings in their seats have led to a very reliable design.

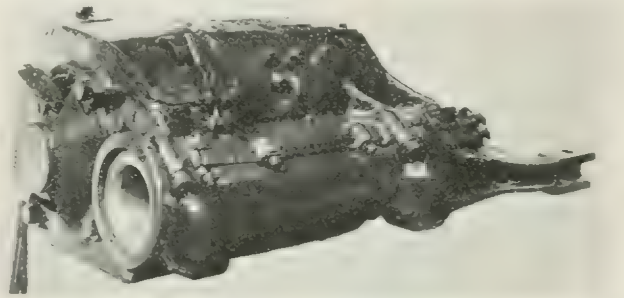


FIG. 9—VIEW SHOWING END AND MIDDLE DUST GUARDS ON A LARGE RAILWAY MOTOR

A further subject in connection with the bearing design is the choice of the proper bearing material. In this connection a distinction should be made between the material of the wearing surface and the material of the shell. The materials for the wearing surface commonly used are bronze, tinned bronze and babbitt. The materials used for the shells may be divided into two classes,—first, materials like bronze or brass which, besides being adapted as a shell, may be used at the same time as a wearing surface either permanently or in case of emergency; second, materials which do not make good wearing surfaces like cast iron, malleable iron and cast steel.

The choice between various materials is to a very great extent governed by design considerations relating to other parts of the motors. It has, for instance, previously been shown that the thickness of axle bearing shells has a certain influence upon the gear center distance and that in many cases it is highly desirable to make the shell as thin as possible. This can best be accomplished by the use of a bronze shell which has good mechanical strength, preferably without a bab-

bitt lining. As a matter of fact space considerations in this respect are in many designs as, for instance, in motors for small wheel diameters, as well as in motors of very large ratings, such that there remains practically no other alternative. Cast iron or steel shells with babbitt lining would, if made mechanically strong enough, require entirely too much space in this case.

In the case of armature bearings, a bronze bearing with or without babbitt lining is usually a little handier from a design point of view, again for the reason that it can be made thinner and that it therefore requires less space than other bearings. This is often important due to the fact that in many designs too large bearings interfere with the effective ventilation.

With regard to cost, it might be stated that as a rule bearings with bronze or brass shells are more expensive than cast iron or malleable iron shells with babbitt. Under normal conditions, that is, with the bronze shells designed as light as mechanical considerations permit, the difference is not excessive. The difference, however, may be quite appreciable if bronze shells are supplied in motors which were designed for iron shells in the first place. The difference may also be appreciable in case of a motor which is designed for large axle diameter and used in connection with a rather small axle because the bronze shell has to be made comparatively thick in this case.

The next point to be considered is the serviceability of the various materials. As a wearing surface, bronze is usually best adapted for low-speed bearings, while with high-speed bearings it is liable to give trouble on account of running hot, especially in the beginning when the bearing is not worn in. Therefore, babbitt lining is usually to be preferred as a wearing surface material in high-speed bearings, such as the armature bearings of railway motors. Wherever bronze is used for the wearing surface, as is most commonly done in connection with axle bearings, the danger of running hot in the beginning is somewhat reduced by giving the bearing a thin coat of tin. Bronze is somewhat superior to many grades of babbitt on account of its greater ability to resist pounding or hammer blows; while this difference is quite marked in the case of a great many cheap babbitts in the market, there is a rather small difference in case of high-grade babbitts,* but even with only a small difference it seems that bronze should be preferred as a wearing surface in axle bearings, because the mechanical shocks and pounding are quite excessive with these bearings, while at the same time their low speed reduces the danger of running hot to a minimum. This latter remark applies especially to larger motors; with smaller light-weight motors, the effect of hammer blows is not so great and it is quite possible to obtain very satisfactory results with babbitted bearings. In armature bearings which are much less subjected to blows and which at the same time are high speed the use of babbitt lining for a wearing surface would seem most advantageous.

There is, of course, a difference between the amount of wear with different bearing materials. This, however, depends so much upon the particular composition of the various bronzes and the various babbitts, as well as upon a large multitude of local operating conditions, such as car and motor weight, motor suspension, schedule of speed, gear ratios, the liability of getting dirt in the bearings, the nature of such dirt, etc., that it is exceedingly difficult to give any reliable general information. It is necessary for the operating man to investigate this point for his own local conditions by comparative tests and investigations.

The material of the shell has also some influence upon the serviceability in the case of railway motors. Where the bearings are always subject to pounding or hammer blows, as mentioned before, a straight bronze bearing or a tinned bronze bearing is best adapted to withstand it. The phosphor-bronze or even the brass bearing with a babbitt lining should be superior in this respect to any of the iron shells with babbitt because the babbitting of bronze shells will permit a complete amalgamation between the bronze or brass and the babbitt, while an actual amalgamation is not possible between babbitt and iron. Wherever the connection between the shell and the babbitt material is not perfect, there is always a chance that the babbitt will pound loose.

With regard to maintenance cost of bearings, the first thing of importance is the number of car miles which can be obtained from a certain bearing; as previously intimated the operating engineer should collect data along this line. The second item of importance is the cost for putting the bearing back into operating condition, or for replacing it, after it has worn a certain amount. An iron or steel bearing can, of course, be rebabbitted at a rather small expense. A babbitted bronze or brass bearing may also be rebabbitted at a comparatively small cost if proper appliances are available to prevent warping, and if the bearing has not been allowed to wear so much that not only the babbitt but also a large part of the shell has worn away, in which latter case it may be necessary to scrap the shell. A bronze bearing if worn, either must be scrapped or, if not worn too much, it may be used again by babbitting it. The scrapping of a bronze bearing, while appearing to be rather expensive at first thought, is found to be rather cheap in many cases on account of the high scrap value of bronze. Many of the larger railway companies use the scrap material themselves for recasting new bearings and obtain thereby a very small cost of maintenance. A further point to be considered is the necessity for scrapping a

*It is of interest to note in this connection that certain cheap alloys can be made to stand up practically as well as some of the expensive tin base alloys, if they are properly handled before and during the process of babbetting.

bearing which arises sometimes due to the fact that the bearing has worn on the outside where it is seated. Such wear is more liable to occur with brass than with bronze, and bronze in turn is somewhat more liable to wear than an iron or steel shell, but with the proper means for holding the bearings in their seats there should not be any wear in either case. In such cases, however, where there is any wear, it is better to have bronze shells, because they wear themselves, while iron or steel shells are liable to wear the housing seat, in case of armature bearings, or the frame and axle caps, in case of axle bearings. This is very objectionable because it is much more expensive and troublesome to replace or repair housings, frames and axle caps, than to replace a bearing shell.

Another point to be considered in connection with maintenance cost is the breaking of shells, either in service or during the process of rebabbitting. There is very little trouble with shells breaking in service except possibly in the case of cast iron shells, the use of which has practically been abandoned for this reason.

For the handling of the bearings in the shop during the process of repair and especially in the case of rough handling, the heavy cast steel shell is, of course,

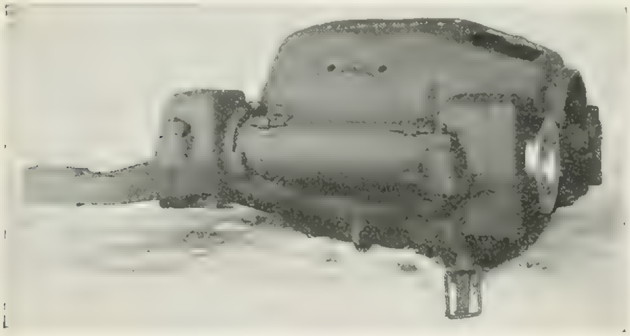


FIG. 10 TYPES OF DUST GUARDS BETWEEN BEARINGS USED ON SMALL MOTORS
This motor was photographed upside down to show details.

preferable to a malleable iron shell and a heavy malleable iron shell is usually preferable to a bronze shell on account of the fact that for design and cost reasons the bronze shells are usually made rather thin; finally, a bronze shell is much superior to a brass shell on account of the superior mechanical properties of bronze. With properly designed bearings and reasonable care in repairing, the item of breakage while handling should not affect the cost of maintenance materially.

The material of the bearing may have an important influence upon the maintenance of other parts of the motor. Of special importance in this connection is the damage which may be caused by an armature coming down on the pole pieces on account of the babbitt melting out of the babbitted bearing. This, of course, is not possible with a non-babbitted bronze bearing; neither is it possible with a properly designed bronze bearing with babbitt lining because it is quite feasible to make the babbitt lining so thin that, even after the babbitt is melted, the shaft can temporarily run on the shell without liability of the armature touching the poles. With an iron or steel shell, the babbitt lining has to be made thicker and, in case the babbitt melts out, the armature will in most cases touch the poles.

With all of the above facts before us, it is evident that none of the possible bearing materials and combinations can combine all advantages, and it seems rather hard to make the proper choice. This means that, here again, there must be a compromise. A great number of leading operating engineers seem to prefer bronze bearings for both armature and that a number also preferred babbitted bearings for both axle and armature while no apparent difference seemed to exist in the operating conditions, thus indicating that there was an opportunity for the railway operating engineers to establish standards for bearings through the railway engineering associations.

As mentioned before, the choice is made easy in some cases as, for instance, in case of axle bearings where there is no room for anything but a tinned bronze shell. But even for other cases, it seems that the best compromise for the axle bearings is as a rule a tinned bronze bearing, although in some cases a babbitted iron bearing may be preferred and will, especially in the case of lighter motors, usually give good all around results. The best compromise for armature bearings seems to be bronze, or possibly a brass shell, with a thin babbitt lining.

DUST GUARDS

Closely related to the bearing design is the design of means for preventing dust from getting into the bearings. Such means are undoubtedly desirable in localities where there is much sand dust which is liable to wear out both the bearings and the shaft or axle. On the other hand, it should be considered that additional parts are required for properly protecting the bearings, and that in some particularly clean localities their up-keep might off-set their advantages. Fig. 10 shows the form of dust guard commonly used on the outside of the axle bearings. Various forms of dust guards have been used between axle bearings. In the case of large motors where the axle caps are very heavy, it is, of course, desirable to have a dust guard which may be removed without disturbing the axle caps in order to permit an inspection of the axle bearings. Such a construction is shown in Fig. 9. In smaller motors, the construction shown in Fig. 10 works out to advantage. It will be seen that small covered openings have been provided for checking the wear in the axle bearings without removing the axle caps and dust guard.

SHAFTS

There is no doubt that for mechanical reasons the shaft should have as large a diameter as possible. There are, however, numerous design objections to a shaft which is unnecessarily heavy; for one thing, a heavy shaft means large bearings,

increasing the weight, as well as possibly the maintenance cost of the same. It is further a fact that in many designs the large shaft and large bearings interfere with the ventilation of the motor. It is therefore again necessary to compromise by giving the shaft a reasonable margin of safety without handicapping the design unnecessarily in other respects. It might be especially mentioned that the strains on the commutator end of the shaft are very small and that there is therefore no necessity for making the shaft at that end particularly large and heavy. On the other hand, it is very desirable to have a reasonably large shaft diameter wherever the punchings are mounted directly on the shaft, a practice which seems quite justifiable for small motors if proper means are supplied for removing the shaft without disturbing the windings or the core. Shaft breakage can often be avoided by providing the proper fillet in the shaft wherever there is a change in diameter.

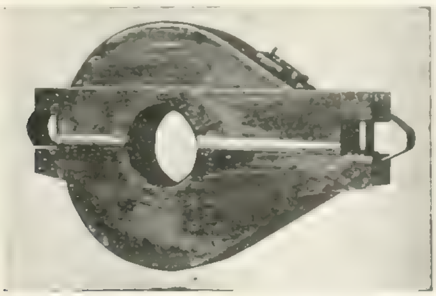


FIG. 11—PRESSED STEEL GEAR CASE WITH TWO-POINT SUSPENSION SHOWING OVERHANGING PORTIONS

GEAR CASE AND CASE SUPPORT

The construction of the gear case and its proper support has been much discussed. Fundamentally considered the gear case is nothing more or less than a receptacle for securely retaining certain lubricants and a guard for protecting the gears from dirt and sand. Anything for filling this purpose properly should be considered a good gear case and it is evident that it does not require anything but a comparatively thin wall of suitable material properly designed to do this. With the urgent necessity for low weight in railway work, it would therefore seem that cast materials, which have to be made rather heavy on account of casting considerations, are not very advantageous, while the use of sheet steel appears to be advisable. The only objection to sheet steel is that a welded gear case is rather hard to keep tight while a pressed steel gear case requires very expensive tools. Wherever large quantities of standard material may be sold, this latter objection is not very important and in such cases the decision should be in favor of the pressed steel gear case without any doubt.

For all other cases, there is the choice between the heavy weight of malleable iron and the liability of leakage of a sheet steel gear case with welded or other joints. Especially for larger motors where the welded joints are more difficult to make, the cast gear case seems almost the lesser of the two evils.

Some operators prefer the cast gear case even to the pressed steel case because they think there is less liability of damage by hitting stones and the like and it may be true that in a few cases heavy cast gear cases have stood up where a pressed sheet steel gear case would have been damaged. On the other hand the cost of hauling around the heavier case should be considered and that a few bumps on a sheet steel gear case may easily be straightened out, while any damage to a cast gear case usually means a new case.

Two methods of supporting the gear case are at present used and are commonly known under the name of "two-point" and "three-point" suspension. Fig. 11 shows a typical two-point suspension. The real fundamental difference between the two suspensions is in the number of points of support, one requiring a greater number of bolts; also the three-point suspension supports the gear case where it is the weakest, while the two-point suspension supports the gear case at its two ends and avoids all strains in the gear case proper. With a very heavy cast gear case and heavy lugs, fair results may be obtained with the three-point suspension. With the sheet steel gear case, however, the three-point suspension means either a very weak construction or the use of very heavy reinforcing pieces reaching around from the side of the gear case, under the gear case, the weight of which means that the main advantage of the sheet steel gear case, namely the small weight, has to be sacrificed to a large extent, In this connection it might be mentioned that a certain small amount of damage to gear cases, as well as to the members supporting it will always be experienced. Whenever the gear-case happens to hit and run on top of some obstruction, a large part of the car weight rests directly on the gear case and its supports; it would require an unduly heavy construction to take care of such accidents.

Another problem to be met in the design of a gear case is to keep the lubricant from getting out of the split and to keep the water from getting in. This condition is very easily met with a sheet steel case as shown in Fig. 12 by the overhanging sheets which serve at the same time partly as supports for the gear case. With cast gear cases space considerations make it practically impossible to provide for protecting overhanging portions, and tightness of the joint can only be secured by very good workmanship. With cast two-point suspension gear cases good results can usually be obtained by clamping a piece of canvas be-

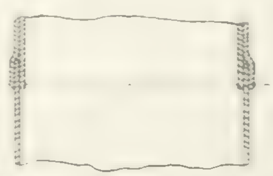


FIG. 12—CROSS-SECTIONAL VIEW OF SHEET STEEL GEAR CASE

tween the machined arms of the gear case supports and the supporting portions of the gear case.

As a matter of course, the gear case has to be provided with an opening on top to permit the introduction of the lubricant. The rim of this opening as well as the overhanging skirt of the cover should be made comparatively high in order to prevent the dirt which usually collects on top of the gear case from falling into the opening. A stiff spring for holding the cover closed during operation should be provided, allowing at the same time a locking of the cover in the open position during the process of lubricating and during inspection.

GEAR AND PINION

The subject of gear and pinion is in itself a very important one, but it is not proposed to cover this wide field here any more than it influences the design of the motor proper. With large ratings which fill the gauge completely the width of the gear influences the motor design in so far as whatever width is used for the gears is not available for the motor. Therefore it is of course not good policy in such cases to make the gears any wider than necessary to be reasonably safe in the gear design.

The pitch chosen for the gears is of some influence upon the motor design in so far as a smaller

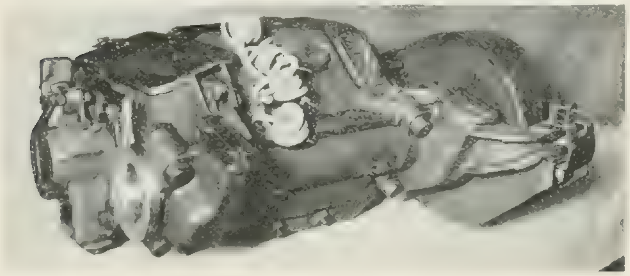


FIG. 13—A SUCCESSFUL TYPE OF SHEET STEEL COMMUTATOR COVER
Shown in place at the left.

pitch permits in many cases a somewhat larger gear ratio. This means at times lower current consumption or in other cases the possibility of using a higher speed and therefore a lighter and cheaper motor. On the other hand too small a gear pitch is very objectionable because it does not give satisfactory operation with the large clearances which are allowed to exist on many properties in the armature and axle bearings. With good maintenance of the bearings, the use of a small gear pitch is, of course, less objectionable; in other words, this is another compromise between power consumption, power cost and weight of motor and maintenance.

It would further be often possible to secure the advantages of a large gear ratio by choosing a very small number of teeth in the pinion; but again we find that, on going too far in this direction, we encounter other difficulties. For instance, too few teeth in a pinion will cause excessive wear; also the small diameter going with a small number of teeth means a reduction of the material between the root of the teeth and the seat of the shaft and keyway. This in turn introduces the liability that the pinion will break, usually between the root of the teeth and the keyway. Sometimes it is possible to improve the situation by using a small shaft diameter for the pinion seat but, of course, it is not advisable to go very far in this direction. A small gain may at times be secured by making an especially shallow key, thereby reducing the depth of the keyway. Again, it is possible to omit the key altogether and secure thereby a stronger hub with a small pinion. This, however, has the disadvantage that there is no safeguard against the running away of the armature in a case where the pinion is not properly shrunk on.

COMMUTATOR COVER

The commutator cover, as well as other covers of the motor serve the purpose of closing up certain holes which are necessary for inspection. Therefore, they are not subjected to any mechanical strains and should be made as light as possible and of material which cannot easily be broken in handling. In other words, sheet steel is the proper material. The occasional use of other materials is possibly excusable in spite of the additional weight in cases where the number of covers is not sufficient to warrant the expense for tools usually necessary in connection with sheet steel covers. While most of the covers are bolted to the frame, it is, in the case of the commutator cover, desirable to have it easily removable, but at the same time securely held against vibrations to prevent its coming off in operation. The sheet steel cover, shown in Fig. 13, is giving very good results.

AXLE COLLARS

In some smaller sizes of motors which do not completely fill the space between the wheel hubs, an axle collar is required, the purpose of which is to fill the empty space on the axle and to present a proper wearing surface to take up the end thrust of the axle bearing. It is, of course, again desirable to keep the weight at a minimum, which purpose has been accomplished by the pressed steel axle collar, in combination with the pressed steel motor. It has been found that a fiber collar on the axle collar represents the best known material for the wearing surface above referred to. Axle collars may be designed to be adjustable to take care of the wear of the axle bearing collars, the wheel hub and the axle collar. If the adjustment is made use of, it is quite advantageous, because small side clearance will materially reduce shocks and hammer-blows, which in turn will undoubtedly have a beneficial effect upon the life of the motor and its parts. The adjustable feature is of course a waste of money, if it is not used, as has been found in a good many cases.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1128—Three-Phase Meter Leads—Is there any reason why the current and potential leads of the same three-phase circuit cannot be run in the same conduit to the switchboard?

J. R. V. (NEW YORK)

There is no reason why all the leads named should not be run in the same conduit.

W. B.

1129—Inherent Reactance of Alternators—Several articles on the subject of protective reactances when dealing with short-circuit currents of generators take the value of such currents to be 100 percent reactance. In an article appearing in the JOURNAL for April '14, and in the reply to No. 1109, it is stated that the maximum possible amount = 180 percent reactance, this being the current obtained when the short-circuit wave is displaced entirely to one side of the zero line. In the case of a three-phase short circuit it is evident that all three phases would not meet this condition and I should like to know how the maximum k.v.a. is determined under such conditions. Should some number between 100 and 180 be used? It seems strange that so many writers have neglected to take account of the phenomenon described, and I should like to know whether this is due to ignorance or to their using a different quantity for "inherent reactance."

E. C. J. (NEW YORK)

In the case of a three-phase short circuit, if the short-circuit current in one phase is a maximum, the peak values of the current in the other two phases will be approximately 75 percent of the maximum possible peak value. The relation between the instantaneous current values in the three phases during the first cycle will be approximately as shown in Fig. 1129 (a). This sketch is based on the two assumptions that the sine component does not decrease in value and that the logarithmic component is constant in value. While this sketch does not show the exact conditions, it does show the typical form of the three curves and the relations between them. Fig. 3, p. 197, of the JOURNAL for April shows the three currents in a three-phase short-circuit, showing the theoretical relationship. From the peak values taken from this oscillogram and given as the first item in Table I, p. 199, it will be noted that the peak value of the A phase is 78 percent of the peak value of the B phase, and that the A and C currents are very nearly symmetrical. Very many oscillograms of three-phase short-circuits do not, however, exhibit this theoretical relation between the three currents. For example, in Fig. 12, p. 105, the peak value of the current in the B phase should be approximately the same height as the peak value of the current in the A phase; otherwise these curves are typical of the correct relation. Very many of these discrepancies in actual oscillograms can be accounted for by the fact that in no case do the three contacts short-circuiting the three phases close at exactly the same instant. Some departure, therefore, from the theoretical relations should be expected. The total k.v.a. at any instant during a three-phase short-circuit could be determined only from the three currents existing at that in-

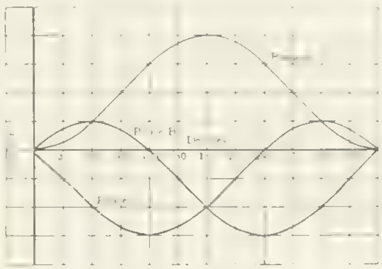


Fig. 1129 (a)

stant and the three corresponding generated voltages. However, the k.v.a. is not of practical importance. The currents only are of importance and usually we are concerned only with the maximum current that occurs in any one phase. Strictly speaking, the voltage existing in any part of the circuit at any time after the instant of short-circuit will be less than the voltage existing the instant before short-circuit. At the point of short-circuit, the voltage in the circuit will, of course, be zero. This reduction in the voltage makes the k.v.a. of little importance. It has been the practice, although with no justification, to speak of k.v.a. and current as being proportional. This, of course, assumes line voltage to exist during short-circuit, which is incorrect. It is believed that the practice of calculating the short-circuit current as 100 divided by the percentage reactance is due to a lack of analysis of the conditions rather than to ignorance. As far as known there has been no difference in the quantity used as inherent reactance.

F. D. N.

1130—25 Cycle Converter on 60 Cycles—What changes would be necessary to use a 300 kw, three-phase, 25 cycle, 600 volt (direct-current) compound wound rotary converter on 60 cycles.

J. T. K. (PENNA.)

A complete new rotating part will be required having greater mechanical strength and fewer armature conductors and commutator bars. The kilowatt capacity will be increased, due to the higher speed. The stator of the starting motor will have to be rewound.

[illegible]

1131—Direct-Current Arc Lamp on Alternating Current—What changes will it be necessary to make in a direct-current, focusing automatic feed arc lamp, to adapt it for use on a 60 cycle circuit. The operating mechanism is actuated by a series coil which is wound on a brass tube with brass end plates and held in position by brass nuts; the core is solid iron; the upper carbon is one-half inch and the lower one three-eighths inch in diameter. I have tried the lamp on a 60 cycle, 110 volt circuit, and find that the metallic parts in the magnetic circuit get very hot.

W. I. H. (DIST. OF COL.)

Judging from the way the question is asked, the only serious difficulty met with has been the heating of the metallic parts of the coil frame. This can be overcome by slotting the metallic end plates of the coil and the central brass tube as shown in Fig. 1131 (a), and by substituting for the solid core one of laminated iron; that is, one made up of thin strips of soft iron riveted together. It will be necessary to use cored carbons and their diameter and that of the holders will have to be changed, as in the alternating-current lamps the consumption of the upper carbon is relatively slower than in the direct-current lamp. If the focusing mechanism is arranged to feed the upper carbon faster than the lower one,

Fig. 1131 (a)

it may be necessary to change the gear ratio in order to secure the proper rate of feed. The amount of light secured for the same watt-consumption will be less with the alternating-current lamp. It will be more economical to use a choke coil with the alternating-current lamp in place of the ordinary resistance wire which is probably in use with the direct current. If the lamp is noisy when operating on alternating current the coil should be mounted on springs.

G. M. L.

1132—Lighting Scheme—In Fig. 1132 (a) is shown a method for controlling an electrolier circuit on the high-tension side at the station switchboard. The load consists of 10 electroliers, each provided with four 60 watt and one 100 watt tungsten lamps. The object is to be able to cut out the lower four 60 watt lamps and leave the one 100 watt lamp burn-

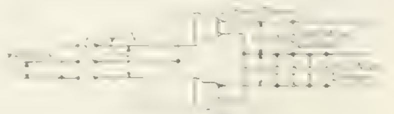


Fig. 1132 (a)

ing. This will require a two kilowatt transformer for the 100 watt lamps and a five kilowatt transformer for the 60 watt lamps. Will the circuit connection with two-pole and single-pole switches arranged as indicated give the desired results? Please note that the five kilowatt

transformer, when the single-pole switch is open, is in multiple with the secondary of the two kilowatt transformer through the resistance of the lower lamps. We have, of course, both the resistance of the lamps and the impedance of the five kilowatt transformer in the lower circuit when the single-pole switch is open. Will this permit a sufficient flow of current through the lower lamps to overload the two kilowatt transformer and would it be detrimental to the service? C. C. N. (NEB.)

This method of control for the lamps will be entirely satisfactory. However, with this connection the middle wire of the secondary circuit must have a carrying capacity equal to the sum of the two outside wires. Hence so far as the cost of copper is concerned there is no advantage in connecting together the secondaries of the two transformers, and two entirely separate circuits may be run. If the distances involved are such that the cost of copper becomes an object, it would pay to reverse the polarity of one of the transformers, in which case the carrying capacity of the middle wire need be only the difference between the carrying capacities of the outside wires when all the lamps are burning. This would, of course, provide ample carrying capacity for the current of the 100 watt lamps when the other circuit is open. With the connection shown or with the polarity reversed as suggested, there is no potential impressed on the secondary of the five kilowatt transformer when the single-pole switch is open, and hence there is no excitation current to this transformer. The load on the two kilowatt transformer in this case will be that of the 100 watt lamps only.

C. R. R.

1133—Cleaning Commutators—Is the use of kerosene injurious to commutator mica, or to the brushes?

J. J. B. (CAL.)

Kerosene or other oils should be used on commutators only as a cleansing agent and then only in very small amounts. It is best applied by means of a cloth slightly dampened by means of the oil, rubbed on the commutator when it is running slowly without voltage. The oil is injurious to the mica (causing it to pit), rather than to the brushes.

F. D. N.

1134—Exciter Trouble — We have three 1 500 kw, 1 500 r.p.m., 370 volt turbine driven generators. The field excitation is supplied by a 125 volt, 300 ampere shunt wound non-commutating pole exciters, regulated by type TA form C6, Tirrill regulators (alternating volts 100 to 125, exciter volts 70 to 140). The exciters are direct-connected to the generators and are in parallel on the switchboard. The regulators are adjusted to maintain normal line voltage at no load with 84 volts on the exciter. The exciter load varies from 75 to 150 amperes and a range of exciter potential of 75 to 110 volts is required to cover the full range of load on the generators. The line load fluctuates from 1 000 to 4 000 amperes per machine. The exciters see-saw and do not divide their loads evenly. The commutators run black a few hours after starting. They have been turned off true and the brushes all spaced evenly at 18.75 bars apart on four-pole machines. (a)—Is the trouble in the exciters or in the regulators? If we would set all the rheostats at the same point to maintain the exciter voltage, cut the regulator out of service, and shift the brush yokes on the exciters until they divided the load evenly, then adjust the relay contacts on the regulator to the same clearance when open and put the regulator back in service, would this help matters? (b)—Should not the regulator maintain normal generator voltage when the circuit breakers open and the load drops to zero? (c)—When the load is taken from the generators is it proper for the regulator to drop out of service and let the rheostats care for the voltage? (d)—What should be the clearance of the relay contacts on the regulator? A. C. (OHIO)

(a)—It is not clear why the load should vary from 75 to 150 amperes while the exciter voltage only varies from 75 to 110 volts, unless occasional hand adjustment is made of the generator field rheostat. No adjustment should be made of the generator field rheostat after the regulator is running, and the rheostats are set to their proper predetermined point. Then the current in the alternator field should vary directly with the exciter voltage. The generator field rheostats should be set to give only 70 volts instead of 80, if possible, at no load. The see-sawing of the load between the exciters may be caused by variations in speed of the prime movers driving the exciters, or the exciter field rheostats are not properly adjusted. These rheostats should be adjusted until exactly six seconds are required for the exciter to drop its voltage from 125 to 25 volts. This will usually mean that the voltage will continue to drop gradually to 7 to 15 volts, after the six seconds. This adjustment should be made with the exciter under load, using one of the alternator fields with the rheostat all turned out as the load; the alternator in this case should not be running. If there is no see-sawing of the speed of these exciters, and the exciter field rheostats are adjusted alike as above, there should be no appreciable exchange of current between the exciters, provided the regulator is in proper adjustment. The regulator is a benefit to the commutation of exciters rather than a detriment, as the regulator holds the minimum exciter voltage required at all times. Before adjusting the exciter field rheostat, the full load neutral position of the brushes should be found, and if this position gives sparkless commutation at no load, assuming the brushes are equally set and properly fitted, they should be marked and left at the full load neutral point, as this will assist in the parallel operation of the exciter. After determining the proper position of brushes on all the exciters, the field rheostat of one generator should be adjusted so that 70 volts on the exciter will give normal no-load alternating voltage. Then, with this rheostat marked in this position, this unit should be shut down, and the fields of this generator used as a load to get the proper adjustment of the other exciters to give the time constants previously stated. This can be done readily with the plant in regular operation, by having one machine on the system taking care of the load, having one exciter running, and placing jumpers from the exciter leads to the fields of the generator. This can be done back of the board, so that the instruments are all in use, as well as the main generator field rheostat. This would not interfere in any way with the exciter bus-bars, as the switch to the exciter bus-bars of the exciter being adjusted, as well as the switch from the bus-bars to the field of the generator which is not running but is being used as a load, would both be open. The generator field rheostat during this adjustment should be set to the predetermined 70 volt point. In this way, the exciter and generator field rheostats can all be readily adjusted, and these adjustments are important in order to obtain the required regulation, as well as proper division of load between the exciters. (b)—Yes. The regulator should maintain the required voltage under all conditions of load provided the generator and exciter field rheostats are properly adjusted as above. (c)—No. It is not proper for the regulator to drop out of service and leave the regulation to the field rheostats if all the rheostats are properly adjusted, as above. (d)—The clearance between the relay contacts when open should be about one-thirty-second of an inch.

A. A. T.

1135—Current Transformers in Parallel—We have two 250/5 ampere current transformers, having the same characteristics, which we intend to use in one leg of a balanced three-phase circuit carrying 500 amperes. Is there any technical objection against connecting the primaries of both transformers in parallel and their secondaries in series as in Fig. 1135 (a) to obtain the correct proportion 500/5?

C. J. M. (WASH.)

There is no objection to operating current transformers as indicated, provided care is taken to keep the primary impedance of the two transformers equal. If connections are carelessly made, the primary impedances due to

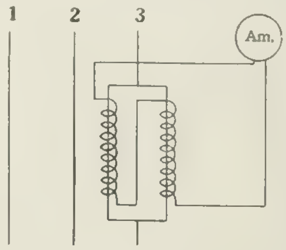


FIG. 1135 (a)

contact resistance at the terminals may be quite different. In such a case the transformer having the lower impedance will develop sufficient voltage to compel practically equal division of primary current between the two transformers. This is equivalent to an overload on the secondary and may cause considerable error especially in transformers of low volt-ampere capacity.

W. R. W.

CORRECTIONS

In the JOURNAL for Sept., 1914, p. 467, Table I, the words "Central Colorado Power Co." should read "Colorado Power Co." The plant capacity of this company is 26 000 k.v.a. and the transmission distance at 100 000 volts is 183 miles. On p. 488 of the same issue "Equation 14" should occur below the three lines which appear just above Fig. 1. In the footnote at the end of this article on p. 489, the last phrase in the numerator of the fraction should be RB^2X instead of RB^2.

THE ELECTRIC JOURNAL

VOL. XI DECEMBER, 1914 No. 12

Progress in Industrial Control

The subject to which this issue is devoted—Industrial Control—should be of especial interest to Journal readers. Very little information on this subject resulting from actual experience has been published. While there are books without number on the design and application of motors and generators, the subject of electrical control is very briefly passed over and the files of our libraries contain scarcely anything on this subject. We do not believe that there has been any intention of slighting control engineering or of creating an impression that it is unimportant, but rather that it is recognized as a field for the specialist. Unfortunately for many engineers in charge of industrial plants and for the younger graduates in electrical engineering who are looking about for a field on which to concentrate, no one has attempted any complete work on this subject.

A little consideration of the articles in this issue on the magnet switch and its accessories, the study and care given to their design and manufacture and the many different applications to procure varied results, will indicate the broad field of possibilities and the necessity for the wide knowledge of apparatus which the successful control engineer must possess. As the successful manager must know the characteristics of the individuals under his charge and so divide their work and responsibilities as not to exceed their respective limitations, so must the control engineer know the apparatus he employs and the work it is to do. This is especially true of work requiring the employment of the magnet switch, since the performance of the controller then becomes automatic or semi-automatic and the parts of the controller, though individual pieces of apparatus, are nevertheless interdependent. The failure of one part, or the oversight and omission of consideration of one necessary function, breaks down the whole scheme of operation.

In the past few years a large number of articles have been written on the subject of scientific management and a number of experiments have proven the possibilities in the way of increased production. In general the principles have been considered as bearing on the human machine—motion study of the individual. The application of an automatic switch controller is a good example of the use of the same principles in the electro-mechanical field. To expand this similarity, it may be said—As the spinal cord and nervous system of the perfected workman, under the training of scientific management, is to his machine and its work, so is the controller to the motor and its work.

We believe the time has come when the motor and controller will be selected for the work they are to perform with as much care and thought as the man is selected for his work. Indeed there are good reasons why they should be selected with greater care. The characteristics of the control, motor and machine are known—can be definitely foretold; the apparatus is not mobile—cannot be shifted easily from one class of work to another until it fits the proper niche; it represents an expenditure which is not cancelled by discharging.

Some manufacturers have been alive to these points and have made a careful study of the work to be performed, and they have found that by the use of suitable control apparatus the required cycle of operations may be performed with much smaller motors than if the motors are not so controlled. They have also found that suitable control prevents overworking their machinery, with consequent heavy repairs due to useless strain put on it at the wrong time and place, resulting in no commensurate gain in output. They have been led to study and report the cycle of operations just as carefully as the expert of scientific management makes motion studies and with the same result—increased product at lower cost.

The efficiency of the automatic electric control of today is the efficiency of the magnet switch, which was introduced as a natural growth of the unit system. Motors of large horse-power were not common in the industrial field at the time of its introduction. Where electric power was employed operators were more or less skilled and the well-known drum type of controller met all requirements. Then came the demonstrations of the economy of electrical installations and the increase in size of units of power. The designers and manufacturers reached the limit at which they could meet the needs with the drum type of controller safely and economically and the industrial superintendent reached the limit beyond which he did not care to entrust his more valuable machinery and output to the judgment of an individual of varying ability and moods. It was evident that the unit system was the only one that would meet the varying requirements, maintain a standard product and keep the expense of special developments within reason by giving the manufacturer the advantage of tools, good patterns and the ability to supply accurate-fitting spare parts.

This has resulted in the magnetically-operated unit switch—not merely a circuit breaker, but a circuit maker as well; not a switch made up of a large number of parts, that can be relied upon to operate a few times a day only, but a switch of few parts, rugged in design, sure in action and able to stand up to its work of millions of operations under the most severe conditions, with few and quickly-made renewals of

parts. To procure a switch which would insure freedom from interruptions of service meant many times its cost to the mill superintendent and master mechanic. Such demands on apparatus not only call for good design and engineering but for excellent workmanship in manufacture—elaborate sets of tools, well designed and well made. The apparatus must not only be the best but reasonable in cost and, where such hard service is required, wearing parts must be interchangeable and renewable with as little trouble and as much rapidity as may be.

This all seems simple—self-evident. The idea of requiring a paragraph to express it. But, it was "a long, long way to Tipperary" as any control engineer, electrical superintendent or manufacturer will tell you. The reason is plain; materials of construction improve, conditions change. The best of yesterday is not good enough for the exacting requirements of today. In the early days the requirements were met, considering the material at hand, probably as well as today, but the striving producer said:—"Since you have successfully done that, do this," and he handed to the designers another and more difficult problem or they set the task for themselves. Then he called for greater speed or scope of work. He again said: "Since the 500 horse-power motor and controller are earning money, let us apply the same type of apparatus to larger equipments—make me a 1 000 horse-power controller." These requirements gave the incentive to the engineer and to the manufacturer and have resulted in the apparatus of today.

It is interesting to note the progress of the art of electrical control as brought out in the present group of articles. These have been contributed by men most closely in touch with their subjects—men who have worked to overcome the limitations of the apparatus of earlier dates and to meet ever-increasing exactments; to look into the future; to do all possible to protect the machinery, the workman and the work; to give maximum production at minimum cost and to eliminate hazard as far as possible.

But the engineer and the manufacturer have not accomplished this unaided. They have been led on and backed up by the users—the mill men, the electrical superintendents, the chief engineers and the operators. Their coöperation and interest, suggestions and pleadings and, many times, demands, have given the incentive to strive for the best attainable. Their assistance is acknowledged with pleasure and the necessity for their forbearance at times, with regret. But whatever the problem, they have been ever willing to add their experience and assist in the solution.

The unit switch, with its accessories, has made the control problems of today soluble. "Tomorrow is another day," but whatever its problems, we have no doubt that the fraternity of designers, manufacturers, engineers and operators which has made the industrial field what it is today, will solve them.

F. D. Hallock

An Appeal for Controller Education

In most electrical installations, the controller is assumed to be a minor detail and, therefore, is not given much consideration. Colleges and technical schools confine their study of this kind of apparatus to a few lectures and problems, and no special text book is available to help those who wish to study further. The natural result of this lack of information is that the controller is a comparatively unknown piece of electrical machinery, and is usually blamed for troubles that are encountered. A controller in its broadest sense is the apparatus which connects a generator, motor or transformer to another electrical machine or to a line. It may regulate the voltage of the generator or the speed and direction of rotation of the motor. It is like a harness to a horse and wagon. It ties the generator to the load or the motor to the line, and governs the voltage of the generator, or the speed or direction of motion of the motor, somewhat as a harness is used to govern a horse and to supply the connecting link between the source of power and the load. No one would think of buying a horse and wagon without a harness, and yet, when you think of it, a harness must receive intelligent care in its construction and selection to give the horse a chance to do his best work. It must not only fit the horse but it must be strong enough to allow the horse to pull the load, and at the same time must provide means whereby the driver can control the horse. A harness maker should know a lot about horses and must also know about the different kinds of work that horses are likely to do.

A controller engineer must understand thoroughly the operation and characteristics of motors and generators; he must consider transmission line conditions; he must have transformer regulation in mind and he must know how to use meters. Good service can often be obtained from a very poor motor or generator by using a carefully considered controller, and the very best of motors and generators can be wrecked by the use of an improperly selected controller. Dynamo designers know about flux densities, about permeability of iron and steel, about hysteresis and windage losses. Controller engineers are not particularly interested in these but are concerned with torque, current consumption, speed regulation, and the effect of variations in field strength on speed and torque, and in addition to all these, they must be thoroughly familiar with the characteristics of all kinds of electrically-operated machinery, such as pumps, fans, machine tools, cranes, elevators, street cars. In other words, they must know what a motor or generator will do, the requirements of the load and how to make the motor or generator fulfill these requirements.

A study of control engineering gives the student a working knowledge of the construction and operation of motors and generators which is different from that obtained when studying the design of these machines individually. He puts himself, figuratively,

in the place of either of these machines to see what it must do to carry the load, and whether the motor be series, compound, shunt, squirrel-cage, wound-rotor or synchronous, he must be familiar with what it will do. This knowledge is also of infinite value to the sales-engineer. He knows what can be done with each kind of motor and he can get unexpectedly satisfactory results with a motor that might usually be considered as entirely unsuitable.

The controller branch of electrical engineering requires therefore a broader and a more general knowledge of the sciences than any other. College and technical school instructors should give it more attention, should study the subject thoroughly and endeavor to understand the importance and the necessity of real controller education. H. L. BEACH

Magnet Control in Steel Mills

The unqualifiedly successful results so far accomplished by the use of the magnet type of control in steel mills, as well as other industries, has demonstrated definitely that the time and attention given to the development and application of this type of apparatus is fully warranted. While much progress has been made in the betterment of operating conditions, there still exists a wide field for further improvement in the nature of changes in existing apparatus and the development of new systems.

The article by Mr. Ahrens on "Magnetic Control for Steel Mill Auxiliary Motors" emphasizes the necessity and importance of improved control systems for the many motor applications of this industry, from the small isolated machine tool motor to mill applications, such as the screw-down, the successful service of which is vital to the continuity of operation of the plant. This is well in accord with present tendencies, for although it has been considered in the past that magnetic control was only practical for the most severe service and larger motor units, it is becoming a more general opinion today that the universal application of magnetic control is warranted with but few exceptions. The small difference in first cost, as compared with other types of controllers, is more than offset by the advantages gained in the majority of cases. In the older forms of magnet control the systems were rather complicated, but now this objection has practically been eliminated.

Safety is one feature of operation, of which the greatest assurance is given by the use of magnetic controllers, and this advantage alone often warrants their adoption. Another advantage, in the case of machine tools in particular, is that greater output is obtained with reduced power and the general efficiency of output is bettered in other ways.

There is much that can be said about the details of design of this apparatus, but the main requisite is to have it reliable and durable and then applied to meet the wide variations in voltage, load, etc., that are more or less common to steel mill operation.

The control systems of today have done much to eliminate the weak features of the older types and designs, and with the many improved and eminently satisfactory designs of motors available at present, a more diligent and persistent effort on the part of the operating and the manufacturing companies to equip these motors properly for their various applications will insure a great improvement in the operation of motor-driven machines. BRENT WILEY

Liquid Rheostats

Liquid rheostats have been used extensively abroad both for starting and controlling the speed of motors used in industrial work. Their use in America has, until recently, been rather restricted but on account of their many inherent advantages, their application is sure to become more general in a short time. However, to make them successful, the conditions of service must be investigated carefully and the installation designed accordingly.

As Mr. Thau has pointed out in this issue of the JOURNAL, the principal advantages of the liquid rheostat are that it affords a means of smooth control, that it is simple in design and economical in maintenance. The liquid rheostat has another advantage which is particularly apparent when used in connection with large installations; that is, its economy of space. In the control of all large alternating-current motors there is the ever-present problem of dissipating the heat wasted in resistance. If a grid resistor is used it must have sufficient radiating surface, and this often means a bulky aggregation of cast iron. With a fluid resistance, the problem is much simplified, as various artificial means of cooling may be used. The ordinary way is to cool the liquid by means of circulating water through it in the same manner that the oil in water-cooled transformers is cooled. Other means are available and have been used. The electrolyte itself may be circulated through pipes located in a cooling pond. The heat in the electrolyte may even be utilized to raise the temperature of water for other purposes, an application which has actually been used in one installation. If water is not readily available for cooling, the electrolyte may be circulated through a system of radiators and cooled by air, and an installation of this sort is now being made. The flexibility of the methods that may be used to get rid of heat is one of the main advantages of this type of control.

To date, liquid rheostats have been restricted almost exclusively to the control of alternating-current motors. In England, however, and I believe in Germany, they have been used to a limited extent with direct-current motors, and with proper design and application there is no reason why their use should not be extended to some classes of direct-current work in this country. GIRARD B. ROSENBLATT

The Magnet Switch

E. A. HANFF

Industrial Control Division,
Westinghouse Electric & Mfg. Company.

THE SUCCESSFUL operation of any machine or piece of apparatus depends as much upon the correct design of its individual elements as upon the method of combining these elements to make up the complete machine. Just as the strength of a chain is determined by that of its weakest link, so is the life or continuity of service of an .lectrical machine affected by the behavior of its constituent parts. There is probably no class of apparatus to which this principle is more applicable than the various types of controllers, and in particular magnet switch controllers.

THE CONTROLLER may be considered as the medium through which a motor may be made to perform a desired service subject to the will of the operator. Whether its function is to assist in putting the motor through a certain cycle of operations, or to guard against the suicidal tendencies of the motor in the event of a ground or short-circuit, each element must perform its predetermined operation, regardless of the frequency with which it is called into action or the severity of the disturbance resulting from abnormal circuit conditions.

E. A HANFF

The variety of applications of controllers is very great and new fields are constantly being entered. In many applications of electricity to industries where the steam or gas engine has long claimed supremacy, the controller engineer is able to simplify the problems of the application engineer often to the extent of making motor applications successful which at first appear to be impossible. To take care of all these various motor drives with uniform success requires the use either of magnet switches of special characteristics to suit each individual case, or of switches in whose design has been incorporated all the features necessary to make their application universal. Commercial policy demands that the manufacturer adopt a few standard types to suit all classes of service; hence it is essential that the requirements of the many different applications be kept in mind in designing a standard switch. In the simplest forms of starters the switches may have to start the motor but once or twice a day, but may be called upon to carry the load current of the motor indefinitely. In the most severe service the motor may be started, stopped and reversed thousands of times a day; in which case the switches will continually be subjected to shocks and must repeatedly open a circuit often carrying several times the full-load current of the motor. These extreme illustrations serve to point out some of the factors that the designer must carefully consider in developing a successful magnet switch.

The evolution of the magnet switch has demonstrated that the "clapper" or open type of construction, while somewhat less efficient magnetically than the plunger or closed type, is by far the most satisfactory. Fig. 1 shows the latest development in this type of magnet switch for direct-current operation and Fig. 5 shows a similar switch arranged for alternating-current operation. In this switch the moving part rotates about a fixed center, thus eliminating any rubbing or tendency to bind, such as is liable to occur in the plunger type of switch, in which the moving member must slide upon parts of the stationary member.

The contacts are designed so that, as the switch closes, the contacts roll upon each other, and at the same time a compression spring acts to force them together, giving a very heavy pressure at the line of contact. To secure this rolling action requires not only a special profile of contact, but also a correct location of the centers of rotation, both of the switch proper and the rolling contact. The rolling feature not only ensures the best possible contact but welding or sticking of the contacts is prevented by the strong prying action brought into play by the contact spring when the switch opens. On all switches above 125 amperes capacity, contact is made and broken upon a carbon block; the final contact, however, is between two copper pieces. The contacts are heavy, and when aided by a magnetic blowout, have an extremely long life. Current is carried from the moving contact to the lower terminal of the switch by a flexible copper shunt and no current flows through the bearings, pins, or springs.

The Magnetic Blow Out is used on all switches which are required to open while carrying any considerable current. The blow-out coil is mounted on the stationary contact and is in series with the contact at all times. The arc shield, of compressed asbestos composition, is built up around the blow-out coil and contacts. The magnetic flux set up by the blow-out coil is distributed by plates placed on the outside of the arc shield in such a way that the arc, when formed, is spread over a large area and quickly extinguished. The arc is blown upward and outward, and away from the sides of the arc shield, so that burning of the contacts and arc shield is reduced to a minimum. The arc shield is hinged so that the contacts may readily be exposed for inspection or replacement.

The Operating Coil is wound on a spool of high dielectric and mechanical strength. After winding, the entire coil is impregnated with a compound, forming a solid mass which is unaffected by moisture or

high temperature. Special care is taken in the design of the spool and winding to avoid open joints or fissures which may allow mill dust to enter and ultimately ground the coil. In some cases the spools are

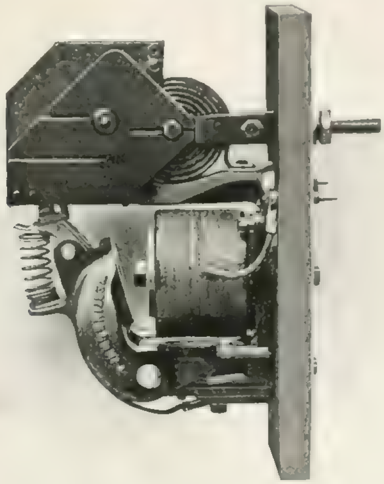


FIG. 1—DIRECT-CURRENT, SHUNT-WOUND MAGNET SWITCH WITH MAGNETIC BLOWOUT

made of a moulded composition which eliminates joints between the inner sleeve and end washers of the spool.

The Mechanical Details, such as bearings, pins, magnet structure, etc., require in their design, careful consideration of the effects of shocks and the wear to which they are subjected. It is chiefly in these details that the various forms of magnet switches differ. Fig. 1 shows a shunt wound direct-current switch. The main bearing consists of a pin or shaft passing through reamed holes in the stationary and movable members. It is held in place by a small locking pin in the larger sizes, and by spring clips in the smaller sizes, and may readily be removed without the aid of

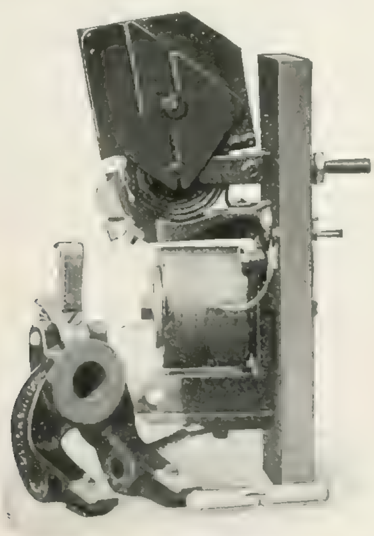


FIG. 2—SHUNT-WOUND MAGNET SWITCH
Dismantled to show simplicity and accessibility of parts.

tools to allow inspection or replacement of coils. The bearings have a large area to ensure long life. The series direct-current switch shown in Fig. 3 is of similar construction but has a coil of comparatively few turns of edgewise wound copper strap. The series switch combines the functions of an accelerating switch and current-limiting relay in a single unit.*

A special form of direct-current switch is shown in Fig. 4. This switch has contacts in both open and closed positions and is used extensively in controllers where dynamic braking or slow-down features are desired. The lower contacts are closed by gravity, but at the instant of contact a circuit is established through a series coil placed upon the lower magnet core, which closes the contacts positively and holds them in that

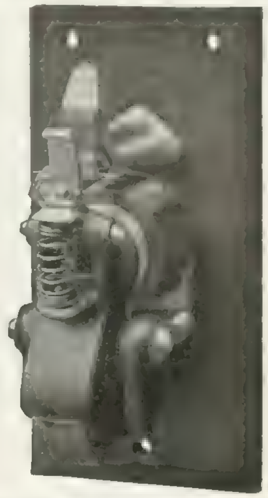


FIG. 3—DIRECT-CURRENT SERIES-WOUND MAGNET SWITCH

position until the current has become sufficiently reduced, or until the circuit is broken. This type of switch allows a dynamic braking circuit to be established in a minimum of time, gives positive interlocking, and prevents reversal of the motor until dynamic

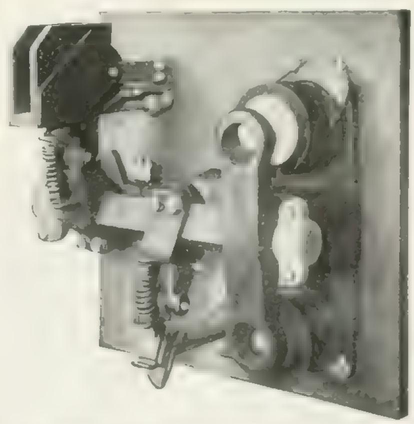


FIG. 4—SPECIAL DOUBLE-THROW DIRECT-CURRENT MAGNET SWITCH

braking has brought it nearly to rest. With this construction, any number of contacts may be placed upon a single shaft, allowing simultaneous closing with a single magnet. The shaft on which the moving contacts are assembled is supported by removable bearings which are mounted on pedestals.

The Alternating-current Magnet Switch shown in Fig. 5 is usually built up of two or more poles, as

*For a description of the characteristics and operation of the series type of switch see article by Mr. W. O. Lum in the JOURNAL for March, 1914, p. 158.

this best meets the requirements of polyphase circuits. The operating magnet is separate from the contacts, and the construction is similar to the direct-current switch just described. The magnet structure is different, of course, and no lower contacts are used. The alternating-current magnet presents problems not met with in direct-current magnets. Punched laminations are built up and supported by a casting in such a way as to insure maximum strength and length of life. A shading coil placed upon the stationary pole face eliminates chattering, giving quiet operation. The contact and blowout details are identical with those of the standard direct-current switch.

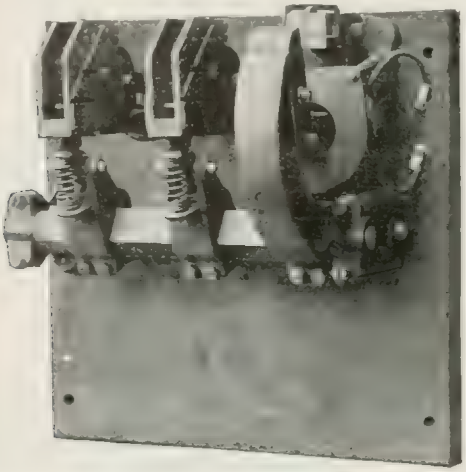


FIG. 5 ALTERNATING-CURRENT, TWO-POLE MAGNET SWITCH WITH BLOW-OUT COILS

Auxiliary Devices, such as master switches and relays, play an important part in magnet switch controllers. The master switch, while called upon to handle but comparatively small currents for the control circuits, must be built ruggedly and adapted to easy manipulation by the operator. The simplest form of master switch is probably the push button, which is used to start and stop a motor, or in some cases to increase or decrease its speed. The more complex forms of master switches employ levers or handles to operate the control contacts. Fig. 7 shows a reversing master switch commonly used on applications requiring frequent starting, stopping and reversal. This type is largely used in steel mill and crane bridge control.

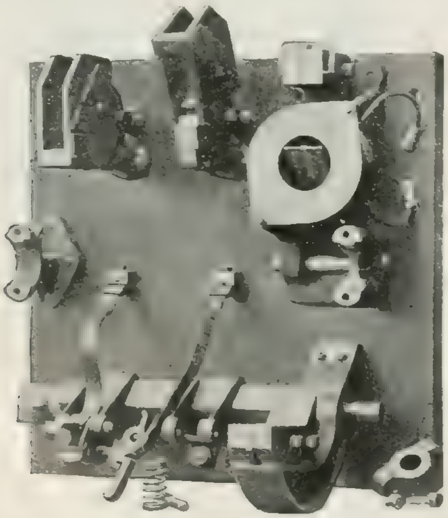


FIG. 6—SWITCH SHOWN IN FIG. 5, DISMANTLED

Showing similarity of contact parts and blow out to those of the direct-current switch shown in Fig. 2.

A type of master switch specially designed for use on reversing planer equipments is shown in Fig. 8. This differs radically from the usual forms in that the contacts are built up as small unit switches which are actuated by a cam connected to the operating lever. Among the advantages of this type of construction may be mentioned:

1—A small movement of the operating lever produces a relatively large opening of the contacts, thus giving a quick opening of the control circuit even though the operating lever is moved slowly.

2—Practically all sliding friction is eliminated, making the switch particularly adapted to the severe requirements of planer service, where several thousand operations a day are the rule.

3—The construction allows the use of "butt" type of contacts, one of which may be carbon, thus minimizing burning of the contacts.

Drum type master switches of a large variety of forms are used where several different control circuits must be handled by the master switch. Where the speed of the motor is to be controlled by means of resistance in series with the armature, as for example in crane hoist applications, a drum controller having several operating points is used. A master switch of this description, provided with a vertical operating handle, is shown on page 682.

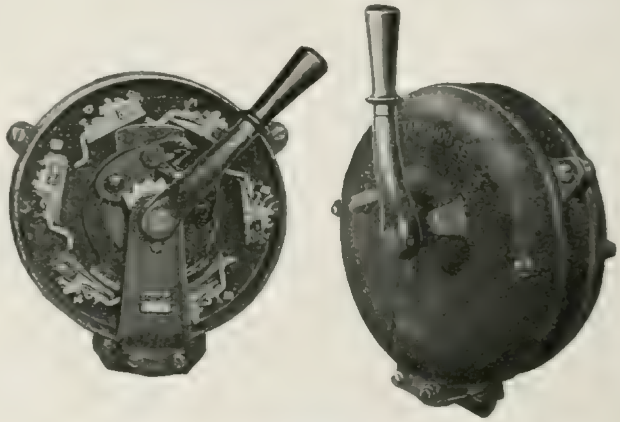


FIG. 7—REVERSING MASTER SWITCH FOR MILL SERVICE

Limit, or Stop-motion Switches, are employed largely as safety devices to bring the motor to rest independently of the operator. The simplest form of such a safety device is the "hatchway" limit switch, which consists of two or more contacts normally held closed by a spring, but which may be opened by applying pressure to a roller on the end of a lever. This type of switch is commonly used in the hatchways of elevators to prevent the car from going beyond prescribed limits. In Fig. 9 is shown a type of limit switch which may be geared to the motor or moving machinery. Any number of contacts may be employed, and as these are operated by adjustable cams, any desired operations of the motor, such as slowing down, stopping, or reversal may be obtained auto-

matically at predetermined points. Geared limit switches are used extensively on automatic skip and bucket hoists, and the extreme flexibility of the cam type of construction makes its application to widely differing requirements a simple problem.

Relays used in magnet switch controllers are designed with the same attention to simplicity and ruggedness that characterizes the magnet switches. Modern practice in automatic controllers demands that electrical interlocks, relays and special devices be eliminated as far as possible for the sake of simplicity in connections. However, in order to protect the motor from damage resulting from abnormal circuit conditions, the use of a certain number of protective relays is imperative. Whenever possible, in direct-current controllers, the series switch is used for accelerating, since its inherent ability to remain open until the starting current has dropped to a safe value permits wiring of the very simplest character and does away with accelerating relays. For applications where it may be desired to operate at speeds lower than normal, the use of shunt switches with accelerating relays is essential.

FIG. 8—MASTER SWITCH FOR USE WITH REVERSING PLANER EQUIPMENTS

The Accelerating Relay is connected in the control circuit so as to close the next succeeding magnet switch when the current has dropped to a proper value, a separate relay being used for each point of acceleration. A mechanically interlocked accelerating relay for direct-current controllers is shown mounted below a magnet switch in Fig. 10 and the details of construction of this relay are given in Fig. 11. Each relay is normally held open by a spring, so that there is no possibility of the accelerating relays closing in any but their proper sequence. When the magnet switch closes, the relay cap is depressed, relieving the plunger and contact disc from the upward pressure of the plunger spring. Just before the cap is depressed, however, the contacts of the magnet switch establish a circuit through the coil of the relay, which holds the plunger in its upper position until the current decreases to the proper value, when gravity causes the plunger to drop, closing the control circuit for the next switch. The current setting of the relay is made adjustable by providing an adjustable air-gap in the magnetic circuit.

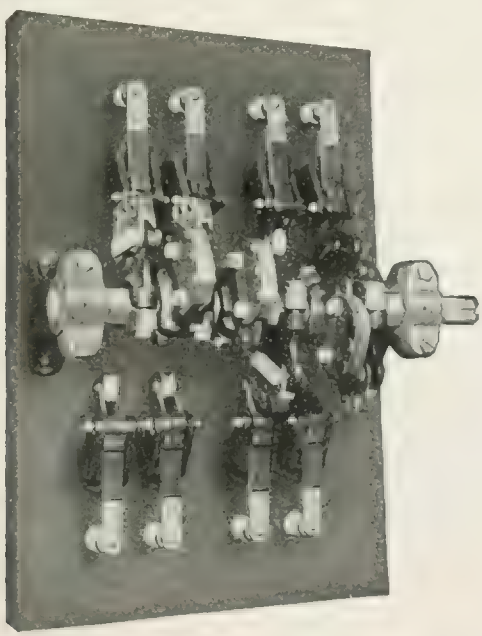


FIG. 9—CAM-TYPE GEARED LIMIT SWITCH

FIG. 10—MECHANICALLY INTERLOCKED DIRECT-CURRENT ACCELERATING RELAY

Mounted on base with magnet switch.

The alternating-current accelerating relay shown in Fig. 12 differs in construction to some extent from the direct-current, but operates on the same principle. As this relay is frequently used in the rotor circuit of an induction motor, it is necessary to so design it that it will operate with uniform accuracy at frequencies varying from 60 down to approximately one or two cycles per second.

The Overload Relay is shown in cross-section in Fig. 13, and two of these relays may also be seen mounted on the upper left hand section of the direct-current controller shown in Fig. 14. The operating coil of the overload relay is connected in series with the motor, and for complete protection two relays are often used, one in each side of the line. When the current reaches a certain point, determined by the setting of the calibrating disc, the plunger rises and strikes the trip pin, which in turn moves the contact bridge lever upward, thus separating the contacts. At the same time a latch operates and holds the lever carrying the contact bridge in an open position. When the relay operates, the control circuit is broken, thus allowing the line magnet switches to open and remove the motor from the source of power. The contacts

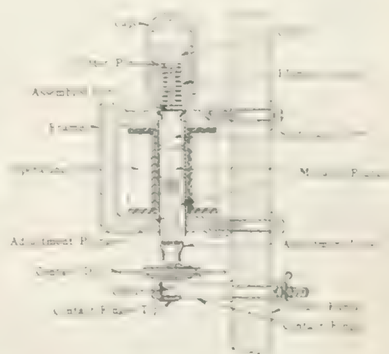


FIG. 11—CROSS-SECTION OF RELAY SHOWN IN FIG. 10

may be reset by depressing the reset lever, either by hand or by energizing the shunt reset coil shown in Fig. 14. For certain applications the latch and reset mechanism is omitted, allowing the contacts to reset automatically. The same relay with slight modifications is used for both direct and alternating-current increments, the action being similar to that of the contacts of a Tirrill regulator.

The Complete Magnet Switch Controller is simply a combination of several magnet switches with the necessary auxiliaries and resistance. The only requirements in its assembly are that the controller

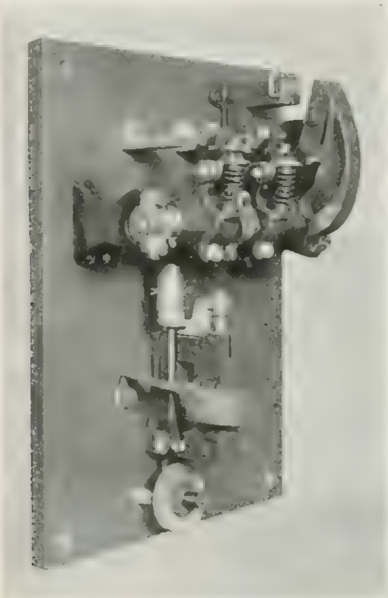


FIG. 12—MECHANICALLY INTERLOCKED ALTERNATING-CURRENT ACCELERATING RELAY

Mounted on base with magnet switch.

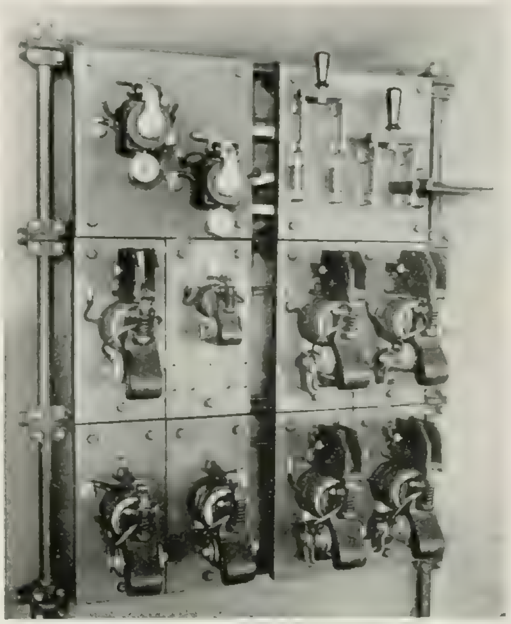


FIG. 14—DIRECT-CURRENT REVERSING CONTROLLER WITH SERIES ACCELERATING SWITCHES

Showing overload relays and method of mounting apparatus on individual bases.

A Low-Voltage Relay serves to open the main control circuit whenever the voltage fails and prevents the motor from being thrown directly on the line upon the return of power. This relay is simply a standard magnet switch of small current capacity provided with a coil so proportioned that the switch will drop out when the voltage drops below a prescribed minimum.

The Field Accelerating Relay shown in Fig. 15 is used on controllers for direct-current adjustable - speed motors, and serves to accelerate the motor to the speed determined by the setting of the field rheostat. The contacts of this relay are connected so as to short-circuit the resistance of the field rheostat whenever the current taken by the motor is above a safe amount. Its use makes it perfectly safe to leave the field rheostat in a position for minimum shunt field current, as the tendency of the motor to take a heavy current is immediately counteracted when the relay short-circuits the rheostat. The relay operates to bring the speed of the motor automatically up to any desired point in a series of small increments, the action being similar to that of the contacts of a Tirrill regulator.

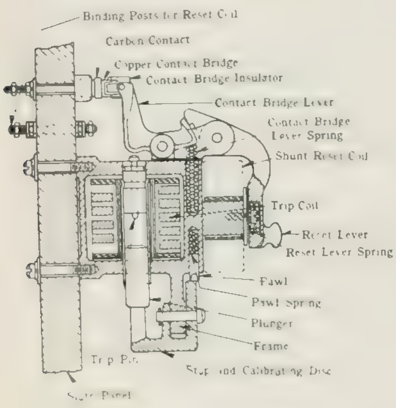


FIG. 13—CROSS-SECTION OF ELECTRICALLY RESET OVERLOAD RELAY FOR EITHER DIRECT OR ALTERNATING CURRENT

proper shall be pleasing in appearance, simple in wiring arrangement, and that the various parts shall be accessible for inspection or adjustment. In the simpler forms of starters, such as are used in machine tool applications, several magnet switches are mounted on a single slate base which is secured to a metal case containing the starting resistance. The starters shown on pages 669 and 670 are good examples of this type of construction. For large controllers, such as are used in steel mill applications, pipe frame construction is used, the switches being mounted on individual slate bases. This type of construction, as indicated in Fig. 14, makes it easy to replace units in a minimum of time and possesses many advantages from the manufacturers' point of view.

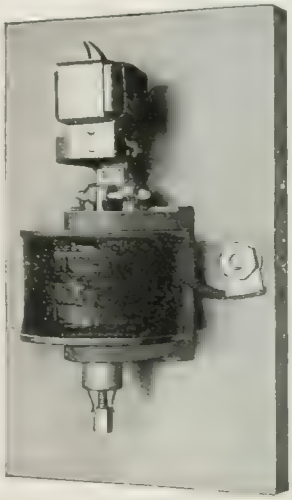


FIG. 15—DIRECT-CURRENT FIELD ACCELERATING RELAY

Important considerations in the design of magnetic switches and auxiliaries, are ruggedness, simplicity and interchangeability of parts. The user who considers the question of maintainance cost and continuity of service will recognize that it is to his advantage to consider such points of design as well as the first cost.

An Analysis of Industrial Control

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Westinghouse Electric & Mfg. Company

THE following discussion outlines the various forms and classes of controllers used in industrial service, giving the relative advantages and disadvantages of each. Fundamental standard forms only are considered, as the design of special apparatus for specific requirements involves simply modifications or combinations or the fundamentals.

THE RAPID development of motor applications would have been impossible without a corresponding development of controllers and starters. The application of motors implies motion; industrial control therefore involves the starting and stopping of motors and controlling their speed. The function of industrial control is to provide a means of starting and controlling the speed of electric motors; to protect the motors and supply lines against heavy current; and to protect the operators against mechanical and electrical injury.

A. G. POPCKE

Industrial controllers can be classified with respect to the type of construction used and with respect to the characteristics of the motors controlled, and will be discussed in this order.

The history of the development of control apparatus is similar to that of other industrial developments. At first, hand-operated controllers and starters were used. Later power-operated controllers were developed, power being supplied principally by means of electromagnets, motors or compressed air. Thus two general forms of control have resulted.

HAND-OPERATED CONTROLLERS

Hand-operated controllers can be divided into face-plate, drum, commutator, switch and liquid types.

The Face-Plate Type is used principally for starting rheostats and small speed regulators where armature control is used. Both armature and field control are often combined in one unit. For starting duty the contacts are made light and the last notch is reinforced for continuous operation. This type of starter is used where a low priced outfit is desired. Besides the low price, it is compact and often is mounted with the resistor as a self-contained unit; it is easy to mount on switchboard or wall; its design is flexible; it can readily be altered for special applications without incurring a large development expense; the renewal of contacts and, therefore, repairs are inexpensive: and protective features, such as no-voltage and overload release can easily be applied. In general, this type of starter or controller can be used where small currents are handled. Its disadvantages arise when applied to applications where large currents must be handled and where ruggedness is essential. It also presents difficulties where complicated connections are involved, as on reversing controllers for wound-secondary induction motors. This type of controller is rarely used where reversing service is required.

Drum Controllers are of medium price. They are compact in construction, but usually have the resistance separately mounted. As they increase in size, the power required to revolve the drum reaches a limit beyond which hand operation is impossible and the cost increases rapidly. In addition to the advantages of medium price and compactness, these controllers can be entirely enclosed and made dust proof and even spray or gas proof. They are mechanically strong and simple to operate, and they can easily be mounted on motor-driven machinery which they are to control, with the controller handle placed in the position most convenient to the operator, motion being transmitted to the controller by means of small transmission shafts and gears. In the case of lathes, for instance, the control handle can be located on the apron of the lathe and motion transmitted to the drum shaft through a splined shaft. To prevent too rapid acceleration, mechanical retarding devices can readily be applied. Complicated connections can easily be made; i. e., forward, reverse, and braking connections can be on the same drum.

When controlling motors of 50 horse-power, 115 volts or 200 horse-power, 500 volts and larger, the disadvantages of this type of control arise. The energy of the arc is hard to dissipate. The contacts deteriorate rapidly under severe conditions of service, and if they are made sufficiently large to prevent this, the controller is difficult to operate and its cost becomes excessive. The drum type of controller is not adapted to special control features as it is difficult to modify its design. It is impracticable to include a no-voltage and overload protective device on this type of controller.

The Commutator or Grindstone Type is used as a reversing controller and is similar to the drum type, the difference being that the fingers revolve instead of the drum. It is possible to break the current at four points, 90 degrees apart, with heavy magnetic blowouts. This controller is of medium price and can be self-contained, with the resistance mounted on a frame. It is mechanically strong and simple to op-

erate, and can be provided with brushes to make it very durable in heavy service. The contacts are easily accessible and can be inspected during operation, but because of the open contacts these controllers cannot be used where this feature would cause danger. They are also difficult to modify in design and are limited in size to approximately 100 to 150 horse-power.

The Switch Controller of the single switch type may be double or single throw, two to four pole, usually with the contacts oil-immersed. This is the type used in starting squirrel-cage motors. A three or four pole, single-throw switch is used to connect squirrel-cage motors up to five horse-power in size (but in some applications up to 25 horse-power) directly to the line. A double-throw switch is used in connection with an auto-transformer to start squirrel-cage motors at reduced voltage before they are connected directly to the line. In the latter case the switching mechanism and auto-transformer may be combined in one unit, constituting the type of starter almost universally used for squirrel-cage induction motors. This forms a very compact unit which is capable of closing and opening circuits carrying heavy currents during starting.

The multiple type is built to handle heavy currents with long life of the contacts. It is flexible in design, strong mechanically, and has the advantage of long life of contacts and positive opening and closing of contacts. Various safety attachments can also be applied. It is more "fool-proof" than the types previously discussed. It is also more expensive than these types, occupies considerably more space and is difficult to operate rapidly. These are made in sizes from 50 to 75 horse-power and above.

The Liquid Controller consists of electrodes immersed in a solution of soda and water. The resistance is varied by changing the distance between the plates, or by changing the immersed area of the plates. The advantages of this type of control are its large thermal capacity, gradual change in resistance, absence of arcing and wear on contacts. The resistance can be adjusted also by changing the strength of the soda solution. The disadvantages of this type of control are that it occupies considerable space; the electrodes corrode; and its application is limited by the use of liquid.

POWER-OPERATED CONTROLLERS

The face-plate, drum and liquid rheostat offer the same advantages and disadvantages when power operated as discussed above for hand operation. Power operation is obtained by the addition of a driving motor, or more frequently, a solenoid, the controller itself being of the same construction as for hand operation. The use of power-operated face-plate and drum controllers for industrial work is rather limited, the switch type being more generally used where automatic operation is desired.

The Magnet-Operated Unit-Switch Controller consists of magnetically-operated switches and is the most durable and most flexible of all types of controllers. Its principal advantages are durability of contacts and mechanical parts. The design is flexible, as it can be used in any application for which electric motors are suitable. The contacts are renewed easily and cheaply; entire units can be replaced; and all parts can easily be inspected. Automatic features and safety devices can be incorporated at a minimum expense. Since the controller proper can be placed near the motor, and independent of the location of the operator, there is a saving in the amount of copper required for wiring. By automatic accelerating devices, the controller can be made absolutely fool proof. The disadvantages of this form of controller are its high initial cost, comparatively large size and weight and the complicated wiring on the back of the panel. This type is becoming more and more popular and its use in practically all applications is increasing because of the "Safety First" feature. The advantages gained also by its reliability and ruggedness outweigh its higher initial cost. Where severe service is encountered, its total cost of operation is less than that of any other type.

The Air-Operated Unit-Switch Controller is, in general, the same as the magnetic type, the switches being operated by compressed air, through electrically-controlled valves. By battery operation of the control circuits it can be made free from trouble due to line drop; it operates more quickly than magnetic control and is more positive in its operation than any other form of controller. Its disadvantages are the use of compressed air which necessitates one more auxiliary to look after; and moisture in the air may cause freezing of the valve parts and failure to operate.

CLASSIFICATION BY TYPE OF MOTOR CONTROLLED

Motors may be classified as follows:—

Direct-Current Motors—

1—Shunt { Constant Speed. / Adjustable Speed.
2—Compound—Varying Speed.
3—Series—Varying Speed.

To start direct-current motors, resistance must be inserted in the armature circuit; first to limit the starting current, thus protecting the motor and line; second to limit the starting torque, thus protecting mechanically the machine operated.. Exception to this is taken in case of small direct-current motors below ¼ to ½ horse-power and also in the case of the so called self-starting direct-current motors that are designed to limit the starting current without the use of external resistance.

To control the speed of direct-current motors below normal speed, resistance must be inserted in the armature. To increase the speed above normal, the field of the motor is weakened by the introduction of resistance. Motors whose speeds are controlled in this latter way are classed as adjustable speed motors and their limit of speed variation is usually four to one. These motors are generally shunt motors, but compound-wound motors are sometimes controlled in this way (limit of speed variation two to one).

On varying speed motors, both compound and series, speed control is obtainable below normal speed only by means of armature control.

All of the above types of direct-current motors are used either in non-reversing or reversing service. In case of reversing service two types of control are used. The motor is reversed by plugging or is stopped by dynamic braking before it is reversed. Dynamic braking is also used in some cases in non-reversing service when it is necessary to stop the machine driven as soon as the power is shut off.

Alternating-Current Motors—

- A—Polyphase induction type
  - 1—Squirrel-Cage.
    - Constant Speed.
    - Varying Speed.
    - Multi-Speed.
  - 2—Wound-Secondary
    - Constant Speed.
    - Varying Speed.
- B—Single-phase induction type.
  - 1—Split-phase.
  - 2—Repulsion induction.
- C—Synchronous.

A—The great majority of induction motors in use are of the constant speed squirrel-cage type. These are started either by connecting directly to the line by means of a switch (up to five horse-power generally and on larger sizes where the application and power lines permit), or by starting at reduced voltage obtained by the use of an auto-transformer or resistance and then connecting the motor directly to the line. These motors are used in non-reversing service with few exceptions.

Varying-speed squirrel-cage motors are used where frequent reversing is necessary and where heavy starting torque is required, as on elevators. These motors are connected directly to the line, usually by means of a drum switch. They are reversed by plugging.

Multi-speed motors are started in the same manner as the constant speed motors just described, but provision must be made to make proper connections of the poles of the motor to obtain the various speeds. A switch on a drum controller is used for this purpose.

All wound-secondary motors are started and controlled by inserting resistance in the rotor circuit. Those of the constant-speed type are usually non-reversing; they are ordinarily employed where the starting torque is heavy but may be used in a few cases where the starting torque is light but line conditions necessitate low starting current. The resistor supplied is for starting service only and cannot be used for running continuously to obtain speeds below normal. For varying-speed service resistance is inserted in the rotor to obtain the desired speed reduction. The resistor must be selected to take care of the load conditions below normal speed. For reversing service the controller must make provision to insert resistance in the rotor circuit and also to change the primary leads for reversing the motor.

TABLE I SUMMARY OF ANALYSIS

Type	Winding	Speed	Controller	Controller Characteristics
Direct current	Shunt	Constant	Face-plate	Low price, compact, non-reversing no-voltage release, overload protection
			Magnet switch	Remote control, automatic acceleration, all protective features, special features as dynamic braking easily applied, most durable, minimum maintenance.
		Adjustable	Face-plate	Low price, compact, non-reversing, no-voltage release, overload protection.
			Drum	Medium price, reversing, protective features separate, adapted to remote control mechanically.
			Magnet switch	Remote control electrically, all protective features, automatic acceleration to any pre-adjusted speed. Most durable, minimum maintenance.
	Series and compound	Varying	Drum	Low price, compact, reversing, contacts enclosed, easily mounted on machine.
			Commutator	Medium price, floor mounting, reversing, exposed contacts.
			Magnet switch	Remote control electrically, automatic acceleration, all protective features, reversing, dynamic braking easily applied, most durable, minimum maintenance.
Alternating current	Squirrel cage	Constant	Switch type	Almost universally used for hand starting, compact, non-reversing.
			Magnet switch	Remote control, automatic acceleration, all protective features, most durable, minimum maintenance.
		Varying	Drum	Reversing, compact.
	Wound rotor	Constant	Face-plate	Used on smaller sizes, non-reversing.
			Drum	For larger sizes.
		Varying	Drum	Reversing or non-reversing, protective features separate.
			Magnet switch	Remote control, automatic acceleration, all protective features, most durable, minimum maintenance.
			Liquid	No wear on contacts, infinite number of steps, large thermal capacity.

B—Single-phase motors of the split-phase type are started by connecting the motor directly to the line. Automatic means is provided on the motor to take care of the starting and running connections. The repulsion induction type is also connected directly to the line. The motor starts as a repulsion type and automatically changes its connections to become of the induction type when the motor reaches a certain percentage of synchronous speed. In cases where reduction in starting current is desired, resistance is inserted in the circuit while starting.

C—Synchronous motors of up-to-date construction, when used in industrial service, are started by the same method as squirrel-cage induction motors.

Furnace Skip Hoist Control

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AMONG the constantly increasing applications of motor drive in steel mill service there is none which has given better results than the automatically controlled motor-driven blast-furnace skip hoist. This drive has relegated practically all steam-driven hoists on the old furnaces to the scrap heap and is installed on all the modern furnaces. The first applications were made probably twenty years ago, and while they were a great improvement over steam driven hoists, it was only with the advent of the modern magnetic switch control that this drive reached its present degree of efficiency and reliability.

THE HOISTS used on modern blast furnaces are of the balanced or two bucket type. Their travel varies from 120 to 160 feet, depending upon the depth of the stock yard floor, and the slope angle is usually between 20 and 30 degrees from the vertical. Three hundred to four hundred feet per minute is standard bucket speed; the buckets weighing approximately 7 000 lbs. and having a capacity varying from 3 000 lbs. coke load to a maximum of 16 000 lbs. ore load. The motors are open type, direct-current, compound-wound, having about 15 percent series field for starting and horsepower capacities varying from 100 to 300.

J. H. ALBRECHT

The modern practice of furnace charging demands a practically constant stock level in the furnace and this necessitates a fairly continuous operation of the hoist. The service is 24 hours per day, seven days per week. The essential features of this service are reliability and continuity combined with extreme accuracy of operation. Any serious interruption in the charging cycle is certain to be disastrous. In a few hours, the stock level is lowered, the protecting layer of "green" stock is consumed and as a result the charging bells and top mechanism are very liable to be burned out if the furnace is not blown out. The loss in time and money is extremely serious.

Accuracy in stopping is absolutely essential. When the bottom bucket is on the bumpers, the top bucket must be over the knuckle in the dumping position. This stop must not vary more than a few inches and must be independent of the load in the bucket. An overtravel may wreck the furnace top and very probably drop the top bucket through the skip house, thus automatically removing any controller which fails to operate.

The illustrations, Figs. 1 and 2, show a controller developed especially for this service. Four single-pole switches mechanically interlocked for reversing and a fifth shunt switch for clearing the negative side of the line are provided. Acceleration is obtained in six steps by means of four series contactors and one shunt contactor and relay on the last point. The shunt contactor is necessary to keep the motor directly on the line in case the motor load drops off as might be the case with empty buckets or in case ore stuck in the descending bucket and it overhauled the motor. The double end switches give slow down in two steps by shunting the armature. The first slow-down switch operates approximately ten feet from the end of travel and simultaneously drops in the starting resistance and applies an armature shunt. Just as the bucket

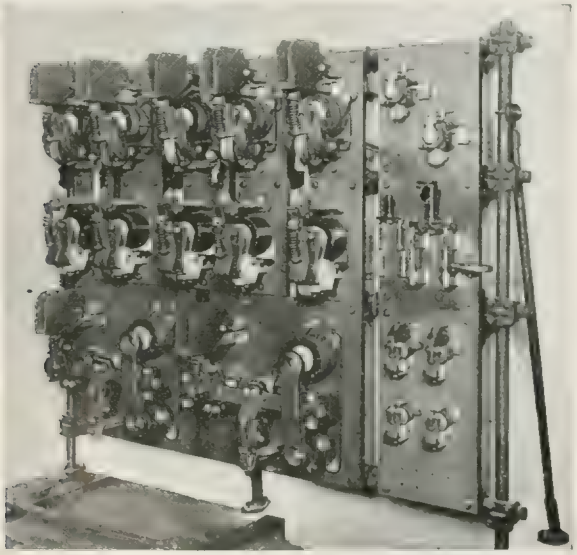

FIG. 1 —CONTROLLER DEVELOPED ESPECIALLY FOR SKIP HOIST SERVICE

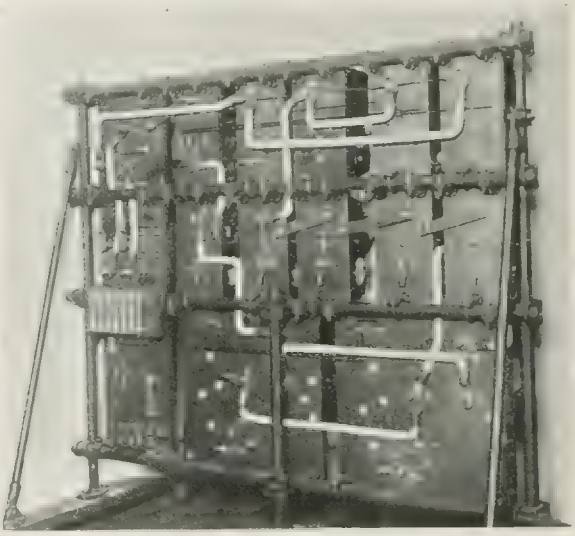

FIG. 2 REAR VIEW OF CONTROLLER SHOWN IN FIG. 1

goes over the knuckle the second slow-down switch operates and applies a more severe armature shunt. Finally, the reversers open and the shunt brake is set by the opening of the two relays shown at the right in Fig. 1. The slow down and stop are obtained automatically by the operation of the cam-type limit switches Fig. 5 which are geared to the hoist mechanism. The motor is started by the operator on the stock yard floor by means of the master controller shown in Fig. 4.

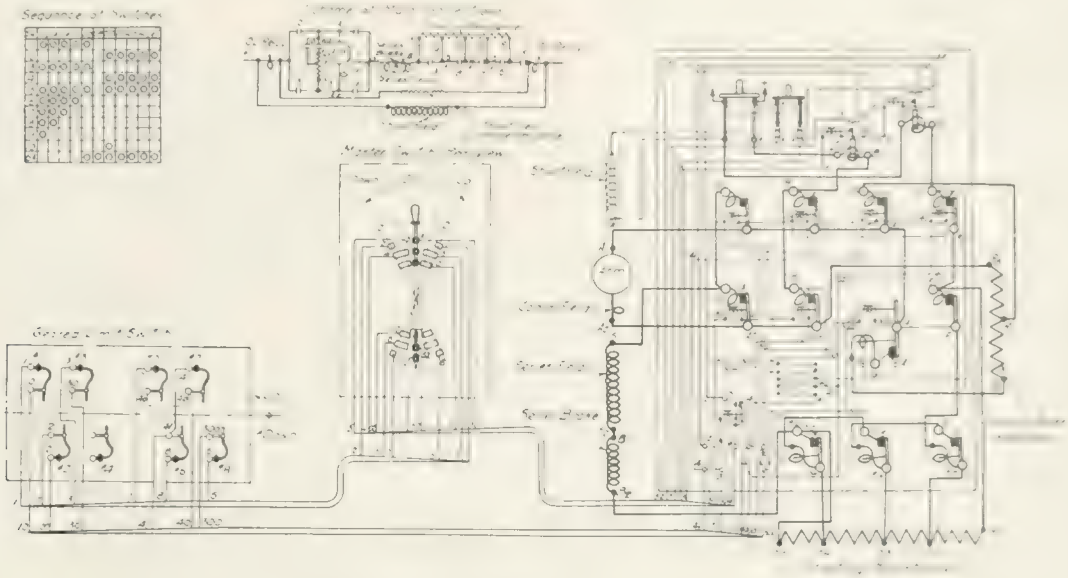

FIG. 3—DIAGRAM OF CONNECTIONS OF SWITCHES FOR CONTROLLER SHOWN IN FIGS. 1 AND 2
Cams *1* and *5* open the circuit at the end of travel in the upward direction.
Cams *2* and *6* open the circuit at the end of travel in the downward direction.
Cams *3* and *8* open switch *6*, giving slow-down in the upward direction.
Cam *7* closes switch *10*, giving slow-down in the downward direction.
Cam *4* not in use. All cams are 30 degrees.

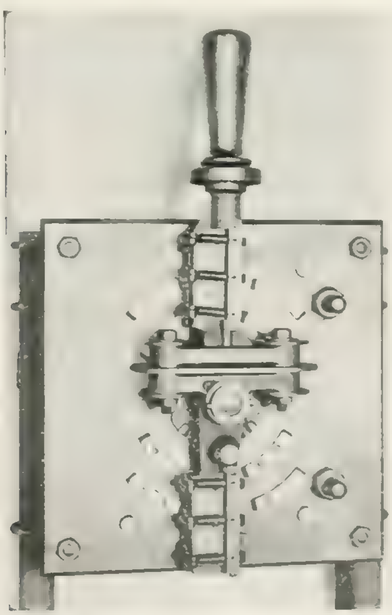

FIG. 4—MASTER CONTROLLER FOR SKIP HOIST SERVICE

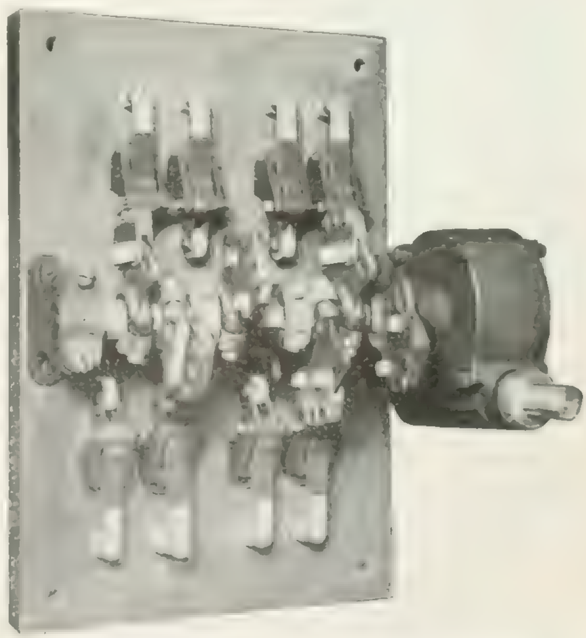

FIG. 5—GEARED LIMIT SWITCH WITH WORM GEAR.

Attempts have been made to devise a set-up device which will act on the slow-down resistance in such a manner as to give a more severe slow down for the light coke loads than for the heavy ore loads. This device was to be operated on light currents and not on heavy currents. The ammeter records show a marked slump in line current when the slow down switch is applied, due to the regenerative action of the motor. This characteristic made the operation of the set-up switch at best very inaccurate and it is evident that any similar device depending for its operation upon the value of armature current will also be unsatisfactory. It has been found that, by a proper adjustment of slow-down switches, a set-up switch can be eliminated. On a skip tested by the writer, the maximum variation in stop from light to heavy load was 1.5 inches.

For safety and simplicity all electrical interlocks have been eliminated. Overload and no-voltage pro-

tection as well as protection against failure of the shunt field are obtained by the use of relays shown on the panel in Fig. 1. Both positive and negative sides of all control circuits and the shunt brake are open on both the master switch and limit switch. A duplicate limit switch is often provided and geared to another portion of the hoist drive. This limit switch has its contacts in series with the first limit switch and provides against mechanical failure of the driving mechanism of either limit switch.

A number of these equipments have been in operation for several years and are giving excellent service, having proven their worth as an insurance against excessive motor and hoist maintenance and delay charges.

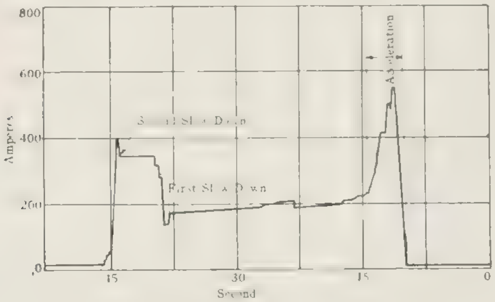

FIG. 6—CURVE OF MOTOR LOAD DUE TO COKE (LIGHT) HOISTING

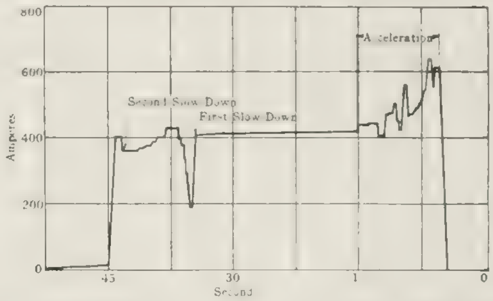

FIG. 7—CURVE OF MOTOR LOAD DUE TO ORE (HEAVY) HOISTING

An Analysis of Diagram Construction

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A DIAGRAM shows in conventional form the electrical connections between the individual parts of a piece of apparatus or between separate pieces of apparatus. It need not be drawn to scale, in fact it would be difficult to make most diagrams to scale and keep them within a reasonable limit of size and clearness. The parts of the apparatus need not be shown in their real positions, but accepted practice is coming more and more to insist that all parts that are mechanically bound together be shown accurately in their relative positions. Conventional pictures are being adopted to represent parts of apparatus. These pictures attempt to show the apparatus with few lines and yet give an idea of its appearance and how it works.

H. L. BEACH

Diagrams as made today are quite different from those made ten years ago, a number of conventions having been adopted so that they will all present a uniform appearance. There are many little "tricks of the trade," however, that do not appear on the surface and yet which are of great assistance in reading diagrams and following the circuits.

Crossings of wires used to be made as in Fig. 1 (*a*). This takes time in the making and is no clearer than the modern method shown at (*b*). Joints or branches were shown as at (*c*). This was very easily passed over so that the modern way was adopted as shown at (*d*). It is frequently desired to join two wires which pass each other and which are sometimes shown as at (*e*). This is not good practice for it is easily skipped and the dot is easily forgotten by the tracer and checker. A much better way is shown at (*f*) which practically eliminates the objections. Another trick by which an apparently complicated diagram can be much simplified is to eliminate double crossing of lines. These appear in the form shown at (*g*). Often the space between the lines may contain other lines and may be in the form shown at (*h*). This can be clarified by the simple expedient of arranging the lines in another order as at (*k*), and it very often develops that the lines may be shown as at (*l*) by other changes elsewhere in the drawing.

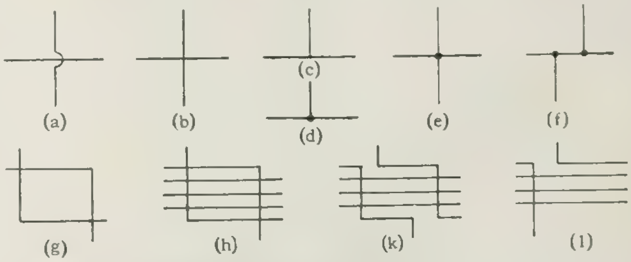

FIG. 1—A COMPARISON OF CONVENTIONS FOR DIAGRAM CONSTRUCTION

A good illustration of the result of care in this matter is shown in Figs. 2 and 3. The older diagram, Fig. 2, is easily recognized. There are 25 crosses in the wires outside the controller of which only one is absolutely necessary as may be seen by referring to Fig. 3. There are other points in the later diagram which tend to assist in making the diagram clear:—The lines

are drawn in two thicknesses, the heavy lines indicating main wires or wires that carry large currents and the light lines indicating small wires or those that carry small currents; the resistances are shown in the same manner, the heavy resistance being for armature

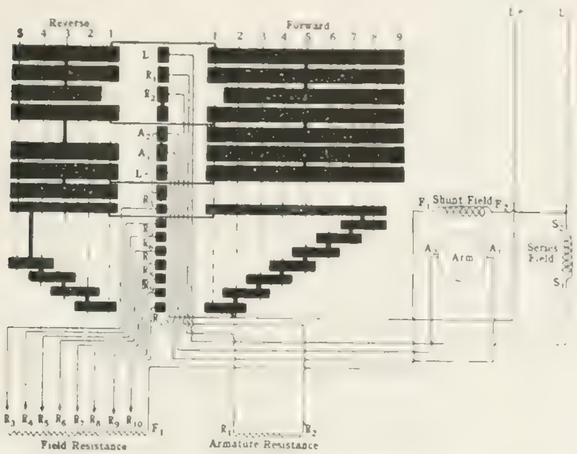

FIG. 2—AN EXAMPLE OF AN UNNECESSARILY COMPLICATED DIAGRAM

starting and the fine resistance for field control; the controller proper is surrounded with a dot and dash line; the end on which the handle is attached is labeled; and the forward and reverse motion is further clarified by arrows showing which way the drum moves in relation to the fingers or stationary contacts.

When automatic control is used the electrically-operated switch usually plays the important role. The controller then assumes the form of a switchboard and the wiring is of two kinds, heavy strap and small wires. The diagram of necessity is simple or complicated as the apparatus is simple or complicated;

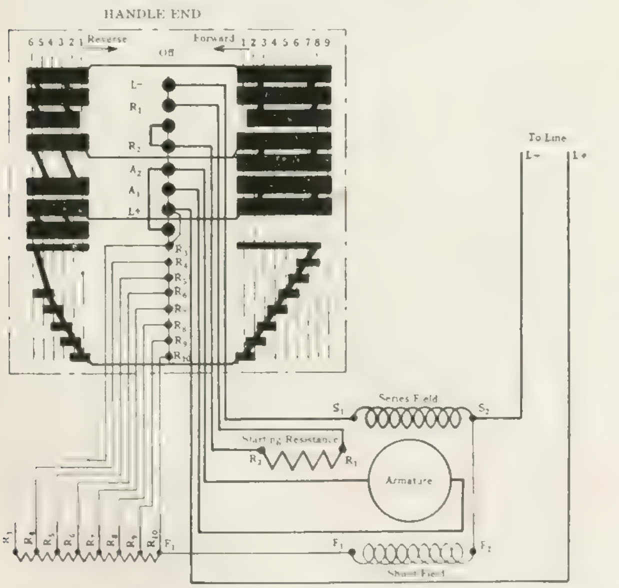

FIG. 3—A MUCH MORE CLEAR AND COMPACT DIAGRAM COVERING THE IDENTICAL APPARATUS SHOWN IN FIG. 2

the diagram of a self-starter of the semi-automatic type, for instance, becomes very easy of construction, as shown in Fig. 4, while that of a push-button operated controller for a wheel lathe, while not by any means the most complicated type of diagram, still presents a much more elaborate aspect than the starter, as is seen by comparing Figs. 4 and 5.

In laying out these panel controllers, the diagram is worked out when the layout is made so that when completed the strap wiring will present the simplest construction possible. This is for reasons of mechanical construction which are self-evident. An illustration of this is given in Fig. 6 in the wiring of four switches used to reverse the armature of a motor. The scheme is shown at (*a*) and two possible methods of connections at (*b*) and (*c*). In each case switches *1* and *2* close to give one direction of rotation and switches *3* and *4* close to give the other. In (*b*) there are three straps requiring bends to clear the terminal studs and one pair of straps cross. In (*c*) there are no crosses and there is only one bent strap.

Another point always to be remembered is that when connecting any piece of apparatus to the line, the part that is best protected from accidental contact

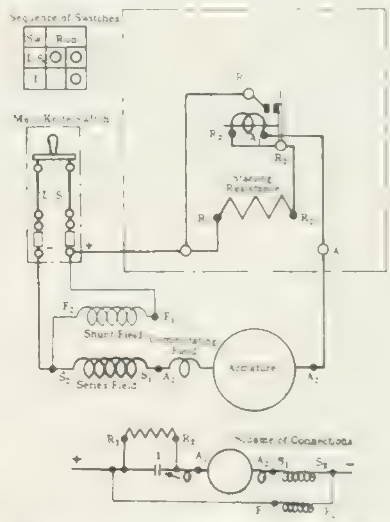

FIG. 4—DIAGRAM OF A SEMI-AUTOMATIC STARTER

should be the line side. This means the break jaws of a knife switch, the stationary contact of a magnet switch, the top contact of a circuit breaker. This is for the protection of operators:—"Safety First."

The control wiring of panel controllers frequently becomes very complicated making it difficult to trace out the connections. Various schemes have been considered for lettering the connections of control wiring to permit ready tracing of circuits. The survival of the fittest is the best test of these schemes and the one that has stood the test of time includes a decimal system. The positive or negative wire from the line goes either directly to the master switch where it is marked + or — or goes through limiting devices such as an overload relay or a travel-limit switch, and finally to the master switch where it is marked *o*. The fingers of the master switch and the wires leading from them are marked *1-2-3*, etc. If it is a reversing controller, wire *1* is ordinarily used for the forward wire and wire *2* for the reverse. These wires lead to the panel and, on the panel, to coils, relay contacts, interlocks, small auxiliary resistances, etc., and finally to the other side of the line. Suppose

that wire *1* goes to two coils in series and then to the minus line. The terminal of the first coil is marked *1*. The other terminal is marked *10* and the first terminal of the second coil, there being no intervening apparatus, is also marked *10* while the other terminal of this second coil is marked (—), as shown in Fig. 7 (*a*). If the circuit passed through some additional switching devices it would be enlarged, as shown in Fig. 7 (*b*). It is seldom that more than six or seven wires come from a master switch and it has become customary to use wire *9* as a common negative wire when there is a limit device on that side of the line. This system in brief may be summed up as follows:—

1—Each wire has a number, *i. e.*, it is named. No matter where it goes it has the same number so long as no coil or interlock or contact or resistance interrupts its circuit.

2—When a circuit goes through a coil, interlock, resistor, etc., the number changes. The primary numbers (*1*, *2*, *3*, etc.) are used for master switch wires and (this is one of the vital parts of the system), these wires step up ten times at the first break in the circuit and then once at each subsequent break. Any wire with a number from *10* to *19* inclusive has its beginning in wire *1*; any wire with a number from *20* to *29* inclusive comes from wire *2*; any wire having a number from *70* to *79* would come from *7*; etc. By this system it is easy to follow back from any point and see at a glance where current comes from primarily.

3—Diagrams are always shown with switches in the position they take when the master switch is in the off position. The wires are then numbered consecutively in the sequence in which they are used. This is of great assistance in tracing the operation of the controller directly from the diagram without the actual apparatus at hand. A good illustration of this is given in Fig. 8. Wire *1* goes to *10*, and *10* connects to several wires through interlocks or relay contacts, but gets its first circuit through wire *11*. Then, after switch *2* has closed, wire *10* feeds to wire *12* through relay contacts and from wire *12* to wire *13* on interlock contacts, closing switch *1*. This opens the connection between wires *10* and *11* and switch *2* opens; whereupon wire *10* feeds to *12*, to *14*, to *15*, to *16* on switch *4*, closing the latter, after which it feeds from *15*, to *17*, to *18*, closing switch *3*, when *15* is connected back to *11* on switch *3*, again closing switch *2*.

The use of these few standard conventions and numbering schemes will be of great assistance to any one constructing diagrams. At best it is not easy to follow out a diagram and those who make it seldom realize the troubles of the individual who has to follow it out without any knowledge of the primary operating scheme. Diagram experts themselves often have difficulty in understanding diagrams made by others, and particularly so when there is no lettering of contacts—no guide to follow out the scheme in mind. Each wire must be traced to its end at once and blind alleys, as it were, are often encountered. A numbering scheme as described here, if used universally, would save many hours of time in understanding "what the other fellow is trying to do."

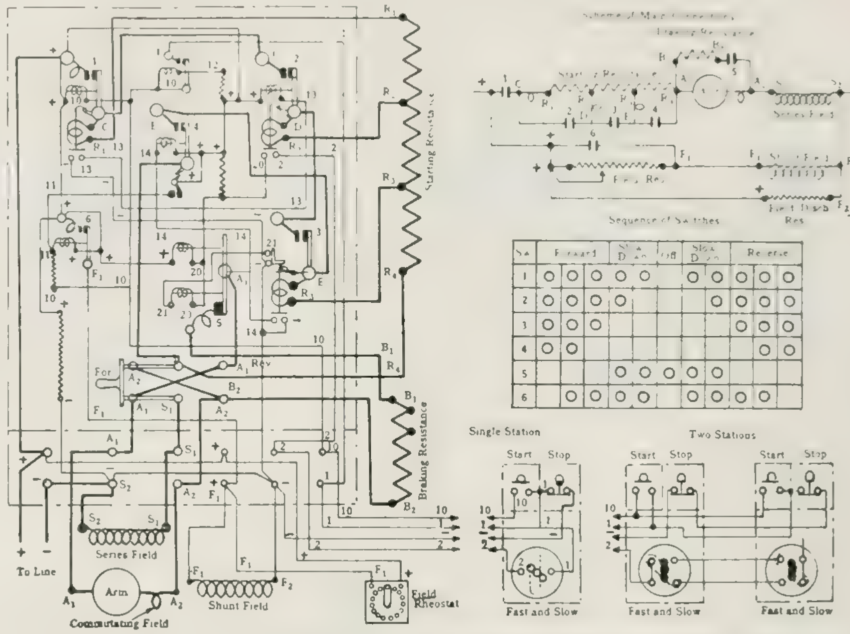

FIG. 5—WIRING LAYOUT FOR A PUSH-BUTTON-CONTROLLED WHEEL LATHE

Compare with Fig. 4. Every attempt has been made in each figure to make the diagram as simple as possible.

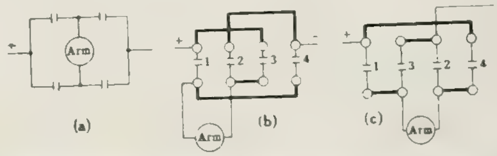

FIG. 6—COMPARATIVE SCHEMES FOR LAYING OUT STRAP WIRING

The comparison between (b) and (c), the schematic diagram for both of which is shown at (a), indicates the possibility of avoiding bends and crosses in the heavy strap.

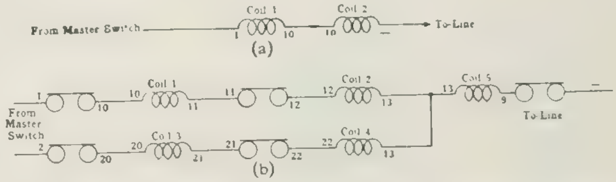

FIG. 7—SIMPLE DIAGRAMS INDICATING THE METHOD OF NUMBERING IN THE DECIMAL SYSTEM

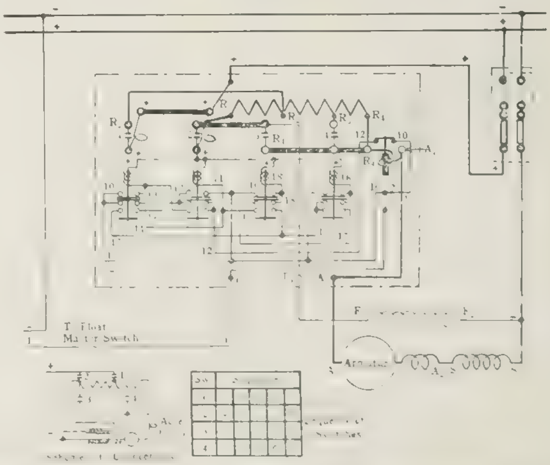

FIG. 8—AN EXCELLENT EXAMPLE OF THE APPLICATION OF THE DECIMAL SYSTEM

The diagram brings out not only the actual connections, but the sequence of operation of the parts.

Automatic Starters and Controllers

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THE USE of automatic starters and controllers for motors driving machine tools, wood-working machinery, compressors, pumps, fans, etc., is becoming quite common, since they offer many advantages over hand control. The principal advantages may be outlined as follows:—

W. H. PATTERSON

1—They give protection to the motors by limiting the accelerating current and automatically varying the time of acceleration, depending upon the load which the motor has to accelerate, bringing the motor to full speed in the shortest possible time consistent with safety.

2—The starters are so simple in operation that wrong operation is an impossibility.

3—No-voltage release and no-voltage protection are given, depending upon the form of the starter. By no-voltage release is meant that upon failure of voltage the switches open, thus stopping the motor, and upon return of voltage the switches automatically close in the correct sequence and bring the motor

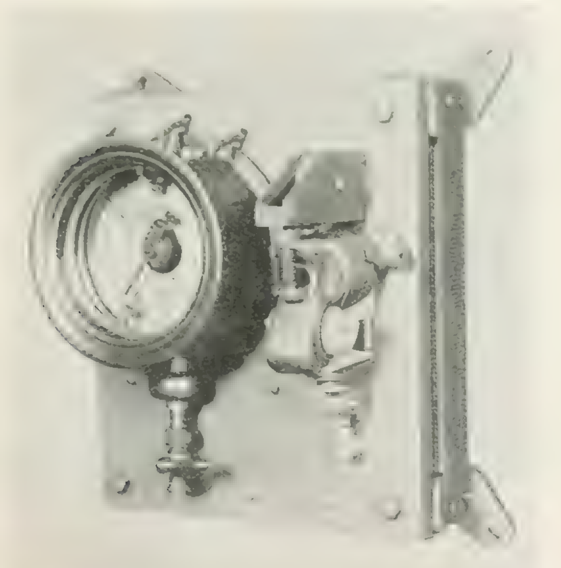


FIG. 1—WESTINGHOUSE PRESSURE GAGE MASTER SWITCH

gradually to full speed. This form of starter is suitable for use with motors driving compressors, pumps, fans, and blowers. By no-voltage protection is meant that, upon failure of voltage, the switch is opened, stopping the motor. Upon return of voltage the switches remain open until the operator pushes a button; hence the operator is protected from injury due to sudden starting. This form of starter or controller is used with motors driving machine tools or wood-working machinery.

4—These starters may also be provided with

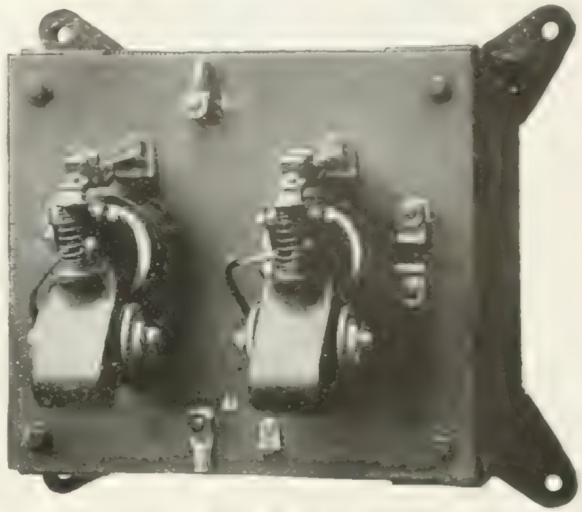


FIG. 2—THE SIMPLEST FORM OF SEMI-AUTOMATIC STARTER CONSISTING OF ACCELERATING SWITCHES ONLY

This requires separate line knife switch.

overload relays which stop the motor in case of severe overload, thus thoroughly protecting the motor and the machinery which it drives.

5—To start and stop the motor it is merely necessary for the operator to push a button or close and open a knife switch. A saving in time is thus effected, as the push button or switch may be very conveniently located near the operator. On large machines a number of push buttons may be located at various places on the machine, all performing the same function, so that the operator does not have to return to the starter to stop or start the machine.

FIG. 3—A SELF-CONTAINED SEMI-AUTOMATIC STARTER

This is similar to that of Fig. 1 but includes on the panel the necessary line knife switch and fuses.

6—These starters can be equipped with pressure gage master switches as shown in Fig. 1, for motors driving air compressors which will automatically start and stop the motor between any pre-determined limits.

For example when the pressure in the tank falls to the lower limit the needle on the master switch makes contact, thus closing the magnet switches on the starter, starting the motor driving the air compressor. When the pressure reaches the upper limit the needle

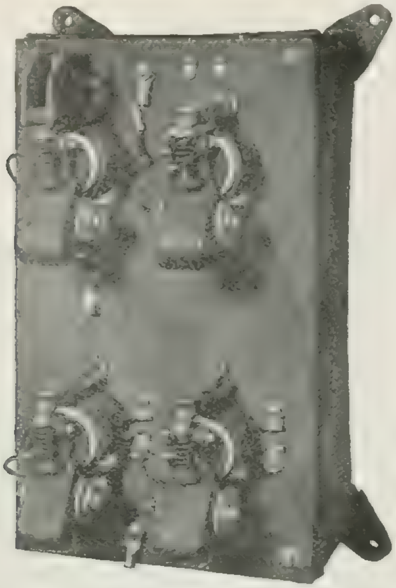


FIG. 4—A STARTER OF THE AUTOMATIC TYPE

The line knife switch of Fig. 3 is replaced by a magnet switch operated by a push button.

of the master switch makes another contact and opens the circuit to the starter, stopping the motor. The starters may also be applied to motors driving pumps and furnished with either pressure master switch or float switch, which will automatically start and stop the motor between predetermined limits.

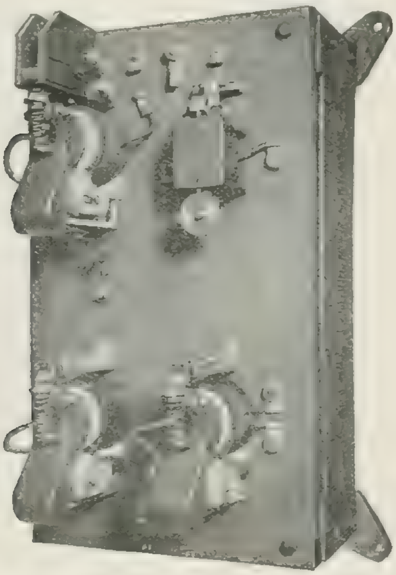
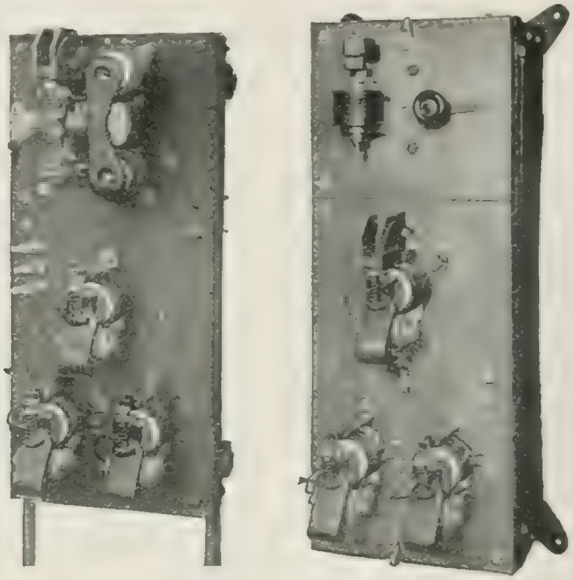


FIG. 5—AN AUTOMATIC STARTER SIMILAR TO THAT OF FIG. 4

Furnishing, in addition, protection by means of an overload relay.

7—Remote control is also possible with this type of starter; thus the motor and starter may be located at some distant point from the button and the operator can start and stop the motor without having to go to the motor and starter.

8—The output of machine tools is increased because the operator is able to start and stop his machine quickly and to accelerate it in the shortest possible time consistent with safety. He does not have to waste time shifting heavy belts or clutches. Also when used with an adjustable speed motor he can ob-



FIGS. 6 AND 7—AUTOMATIC STARTERS FOR USE WITH ADJUSTABLE SPEED MOTORS

Fig. 6 is a machine tool starter providing quick stopping by dynamic braking through the back contact of the line magnet switch.

Fig. 7 is similar in its starting switches to the simpler starter, but is equipped in addition with field rheostat and accelerating relay.

tain exactly the right maximum cutting speed for the work at hand.

Automatic starters and controllers are made in a variety of forms to meet the different classes of serv-

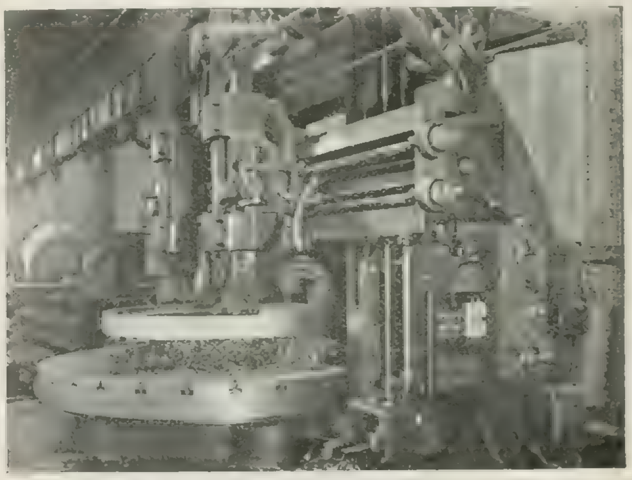


FIG. 8—A 100 INCH BORING MILL

Driven by a 20 horse-power, 230 volt, 500 to 1 500 r.p.m. direct-current adjustable speed motor with push-button automatic magnet switch starter.

ice and applications of motors. Only the most common of these are covered in this article. The simplest form, Fig. 2, consists of two series accelerating magnet switches and the necessary armature resistance. With this starter it is necessary to use a separate knife switch. Upon closing the knife switch, the motor is connected to the line with resistance in

series with the armature. The magnet switches automatically close, cutting out the armature resistance and bringing the motor to full speed. By opening the knife switch the motor is stopped. Fig. 3 is the same form of starter as Fig. 2, except that the knife switch and fuses are mounted on the starter. Both of these forms of starters give no-voltage release.

The form of starter shown in Fig. 4 consists of one shunt line magnet switch with blow-out coils and the necessary series accelerating switches and start and stop push buttons. Upon pushing the start push button, the shunt line magnet switch closes, connect-

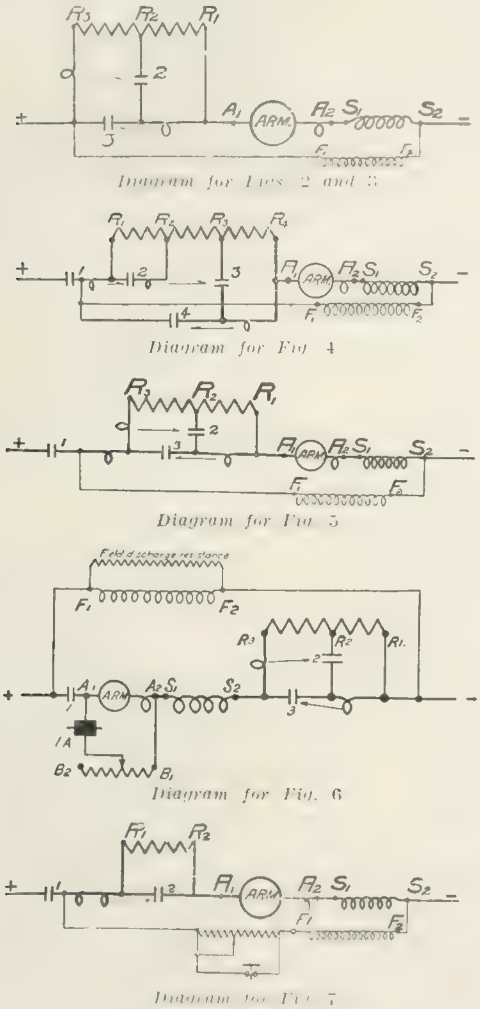


FIG. 9—DIAGRAMS OF CONNECTIONS

Showing schematically the operation of the starters shown in Figs. 2 to 7 respectively.

ing the motor to the line with resistance in series with the armature and then the series switches automatically close, cutting out the armature resistance and bringing the motor to full speed. Upon pressing the stop side of the push button, the switches open, stopping the motor. This form of starter is made to give either no-voltage release or overload protection.

Another starter, shown in Fig. 5, has the same characteristics as that in Fig. 4, except that it is equipped with an overload relay which, in case of heavy overload, opens the magnetic switches, stopping the motor, thereby protecting the motor and the machine which the motor drives. This relay is made in three types for different services:—First, shunt reset, which is reset by pushing a button, bringing the master switch to the "off" position; second, hand reset, which

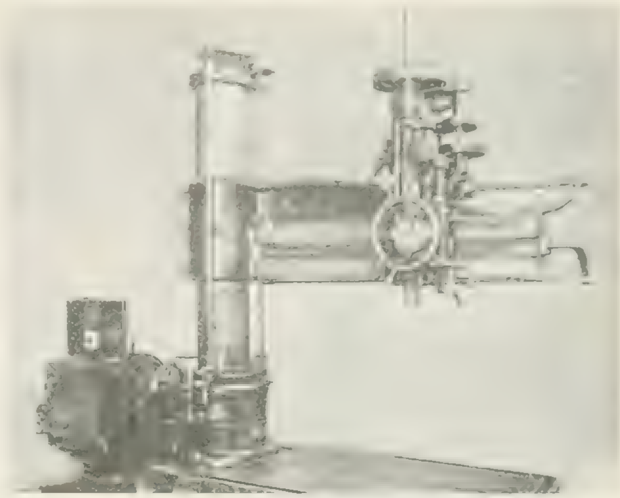


FIG. 10—A SIX-FOOT RADIAL DRILL

Driven by an 11 horse-power, 230 volt, 450 to 1 800 r.p.m. direct-current adjustable speed motor vith push-button automatic magnet switch starter.

must be manually closed at the controller; third, automatic reset, which is closed automatically as soon as the overload is removed.

A starter with a shunt magnet line switch, blowout coil, a back contact, and the necessary series accelerating magnet switches is shown in Fig. 6. This type of starter is equipped with start and stop push button stations and gives no-voltage protection. It is similar in operation to the starter shown in Fig. 4, except that upon pushing the stop side of the push button, the shunt line magnet switch opens and the back contact closes, inserting resistance in shunt around the armature of the motor, thus giving dy-

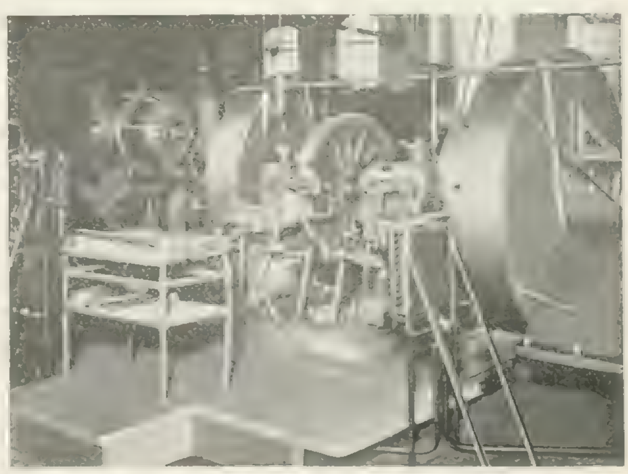


FIG. 11—AN AUTOMATIC CONTROLLER APPLIED TO A CAR-WHEEL LATHE

namic braking and stopping the motor very quickly. These starters are especially adapted to wood-working and machine tool service. They may also be equipped with overload relays where desired.

The form of starter shown in Fig. 7 gives no-voltage protection and is used with adjustable speed motors for the operation of wood-working and machine tools. It consists of a shunt line switch with blowout coils, the necessary series accelerating magnet switches, a field rheostat to cover the speed range of the motor, a field accelerating relay to accelerate the motor to the speed corresponding to the setting of the field rheostat and a start and stop push button station. Such a starter, applied to a 100 inch boring mill, is shown in Fig. 8, and a similar one operating a radial drill is shown in Fig. 10. These starters may also be equipped with overload relay and dynamic braking features where desired. The schematic diagrams for the various starters are shown in Fig. 9.

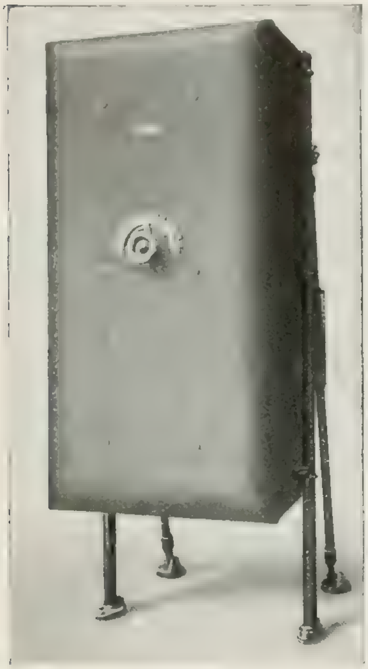


FIG. 12—WHEEL LATHE CONTROLLER WITH COVER

Fig. 11 shows a car wheel lathe equipped with a direct-current adjustable speed motor and automatic controller,* and the latter is shown with and without its cover in Figs. 12 and 13. In turning down locomotive and car wheels, hard spots are frequently encountered, and unless these are cut at low speed the cutting tool is apt to break. On the other hand the remainder of the wheel may be cut at a much higher speed in order to obtain economical production. The operator cuts the soft part of the wheel at a high speed and when a hard spot is reached reduces the speed to the proper value by pushing the button; and when the spot is passed the normal cutting speed is resumed. In this way the cutting is done at the most efficient rate, the expense and delay due to breaking of tools are eliminated and the time of setting up work can be greatly reduced because the operator can start and stop the lathe without leaving the cutting tool.

FIG. 13—CONTROLLER SHOWN IN FIG. 12 WITH COVER REMOVED

The controller consists of a slate panel on which is mounted a shunt magnet line switch, a dynamic brake magnet switch and the necessary series accelerating magnet switches; also a double-throw knife switch to reverse the motor if necessary. An enclosing cover is a feature of the controller for this service and a field rheostat for adjusting the motor speed is separately mounted on the cover of the controller.

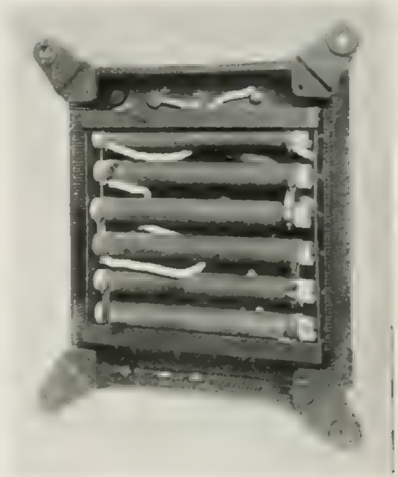


FIG. 14—BACK VIEW OF A WALL-MOUNTING STATOR, SHOWING RESISTORS

The operator controls the motor by means of a set of four push buttons marked respectively—"start," "stop," "fast" and "slow." Any number of stations can be supplied, but more than one are seldom required. The field rheostat is adjusted to give maximum desired speed for the soft part of the wheel. The "start" button is first pushed and then the "fast" button. The motor is then automatically accelerated to the speed fixed by the setting of the rheostat. It makes no difference how quickly the "fast" button is pressed after the "start" button. The motor acceleration depends upon a predetermined setting of the controller and cannot be altered by by the operator; hence he cannot injure the motor by too rapid acceleration. The motor is always started with full field which is weakened automatically after all the starting resistance is cut out. When a hard spot is reached the "slow" button is pressed, the motor then operates at slow speed until pressing the "fast" button brings the motor to full speed again. When the "stop" button is pressed the motor is quickly brought to rest by dynamic braking.

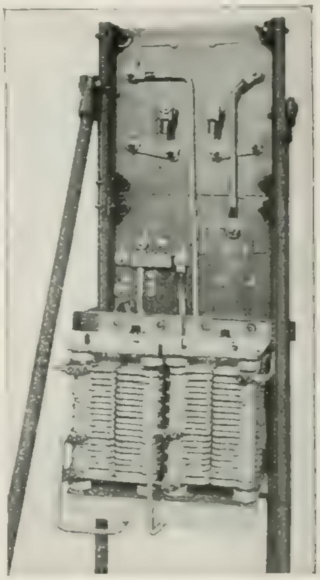


FIG. 15—BACK VIEW OF FLOOR-MOUNTING STARTER, SHOWING GRID RESISTORS

*For diagram of this controller, see Fig. 5, p. 668.

Magnetic Control for Steel Mill Auxiliary Motors

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ONE of the most important factors in connection with the rapid progress made in recent years in the application of electric power in the steel industry has been the development and perfection of magnetic control with its application to motor drives. Magnetic control was first used in the steel industry about ten years ago. It was applied on ore unloaders, where remote control was desired, and later to the severe reversing work incident to the operation of the mill and the actual rolling of the steel, on such applications as mill tables, where automatic acceleration with protection to motor and machinery was desired. As the general advantages of magnetic control became more apparent, its use became more general, and with the recent improvements in control systems, as offered by series switches, double throw switches, etc., minimizing the wiring and connections, and simplifying the systems in many other ways, together with the reductions in cost that have resulted, its application is becoming much more general.

MANUALLY-OPERATED controllers are limited in their use as regards size and power to operate them. In sizes above 75 horse-power, 230 volts, the manually-operated controller is too large to be mounted conveniently to the operator, especially where the resistance is mounted in a frame integral with the contact making devices, and the physical power required to operate it in mill practice is too great for one man. In the best modern practice, magnetic control is used on all motors of 50 horse-power, 230 volts, and larger on intermittent duty, and on smaller motors where the service requires it. With the increased capacity of mills and cranes now being installed, motor units of larger size are coming into more general use and this is resulting in greater and more general use of magnetic control.

A. G. AHRENS

The labor employed to operate the motors in the mills is often of a type which is irresponsible and will not follow instructions to allow sufficient time for reversing and accelerating the motors with manually-operated control; and as a result the motor and the mechanical equipment suffer severely. On cranes, charging machines, strippers and like machinery, and in the operation of the mill tables, manipulators, screw-downs, etc., one operator often has charge of three to five controllers and operates two or three of them simultaneously; in such cases, even where the operator is fairly intelligent, he is often tempted to crowd and abuse the equipments in order to gain time. With the use of magnetic control, proper protection is insured to the motor and equipment, independently of the operator, eliminating the extraordinary delays and repair expense connected with the use of the manually-operated controllers.

On a stock yard crane, the trolley motor with manually-operated control often has to take two to three times its normal current, due to "plugging" the motor at full speed. The resulting sudden change in speed racks and strains the motor and crane equipment and actually means a loss in time, as such conditions are unfavorable for the rapid stopping and acceleration which are necessary to handle the stock in a satisfactory manner. With magnetic control, the motor current can be limited to safe values, insuring stopping and acceleration of the motor without abuse of the equipment and, at the same time, maximum economy of time can be effected, independently of the operator.

The screw-down of a two-high, reversing mill is an example of the severity of conditions that may be imposed in mill service. The motors on this application are used to adjust the space between the rolls, raising or lowering the top roll. The rolls, in general, are adjusted for each pass, while the steel is on the receiving table and the rotation of the rolls is being reversed. The time allowed for adjustment of the rolls varies with the type of mill and work done, but is not more than two seconds. This can be appreciated better, when it is stated that an ingot can be reduced to a bloom in two minutes, making 19 passes in that time, and this is not extraordinarily fast mill operation, but is simply rolling practice on a certain mill.

With manually-operated control, on a certain mill, the armatures had to be replaced approximately every two weeks, frequently requiring new coils or new commutators. About two years ago, a magnetic controller similar to the one described below was installed, and so far the motor armatures have not been changed or repaired since the installation of the magnetic control. The normal full-load current of the motors (there are two in series) is 300 amperes. With the magnetic controller, the peaks are approximately 700 amperes, while with the manually-operated controller the peaks exceeded 1 000 amperes, resulting in severe electrical and mechanical shocks to the motors. Considerably faster operation is now obtained, which has increased the output of the mill.

The functioning of the controller and the necessity of selecting controllers with durability and simplicity as their main features can better be appreciated when it is stated that the armature current of the

motors is reversed 150 000 to 200 000 times a week, and the controller must make and break the circuit for each reversal. This is the sort of service for which the controllers are designed, however, and to date they show no signs of wear except on the contacts, which are replaceable, and are renewed as required on individual switches, after they have made from one and one-half to two million breaks.

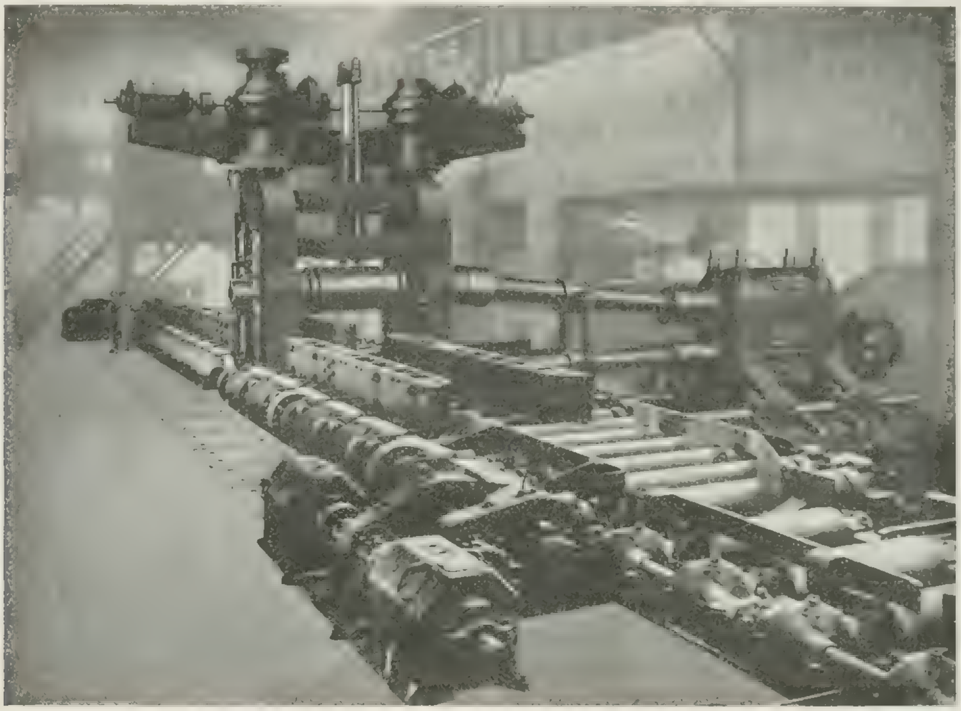

FIG. 1—REVERSING BLOOMING MILL SHOWING MOTOR DRIVEN SCREW DOWN AND ROLL TABLES

The Construction and Mounting of the Apparatus are extremely substantial, as shown in Fig. 2, each switch being assembled on an individual base, which is mounted on a pipe framework. Each switch is detachable, without disturbing the other parts, and the arrangement is such as to permit adequate inspection and renewal of wearing parts with minimum delay. The simplicity of the connections and the absence of interlocks with a multiplicity of contacts and the accompanying wiring are particularly noticeable.

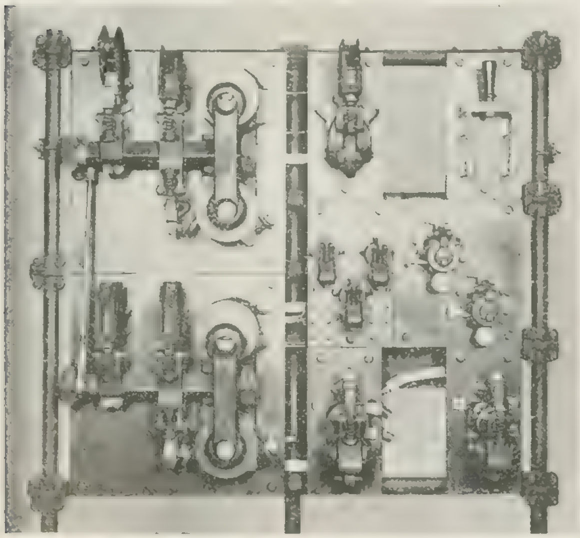

FIG. 2—CONTROL PANEL EMPLOYED IN THE OPERATION OF SCREW DOWN MOTORS IN STEEL MILLS

The two double-pole switches close by means of shunt coils, and are mechanically interlocked so that both cannot be closed at the same time. Each double-pole switch is provided with a back contact, which closes when the switch is in the open position. These contacts are shown as *2-A* and *1-A* in Fig. 6, and when closed connect the braking resistance directly across the armatures. The back contacts are provided with series holding coils, so as to insure good contact when carrying current.

FIG. 3—FLOOR CHARGING MACHINE EQUIPPED WITH MAGNETIC CONTROL

There are four motors under the operator's control on this machine; namely, hoist, trolley, peal and bridge travel. The operation is to lift boxes from in front of the furnace, to raise and carry them f rward and to invert them inside the furnace.

The two single-pole magnet switches for the resistance notches (three for 100 hp motors and larger), shown in the diagram as *7* and *8*, are of the

series "lockout" type. Series "lockout" switches cannot close until the current has fallen below a certain value, which is capable of regulation by adjusting a knurled nut at the end of the lower magnet arm. The use of these switches avoids the necessity of series relays and interlocks and their accompanying complications. Switch *7* is provided with an operating coil only, while *8* has both operating coil and series "hold-

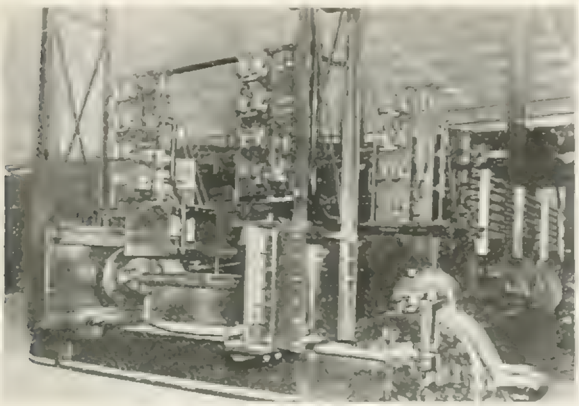

FIG. 4—END VIEW OF CHARGING MACHINE OF FIG. 3, SHOWING CONTROL APPARATUS

in" coil. The "hold-in" coil is put in series with the operating coil, after the switch is closed. This provides a coil of a comparatively large number of turns, which holds the switch closed during periods when the current is light.

Overload Protection is provided for by means of two overload relays (one on each side of the line), shown in the diagram as *OL*. After the overload relays have operated, they can be reset by bringing the master switch to the "off" position. The overload protection providing for opening up both sides of the

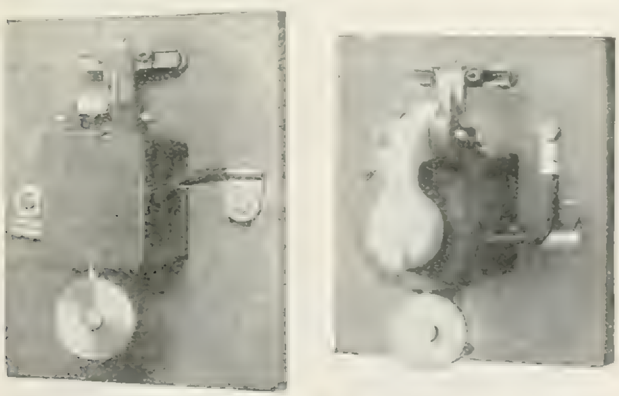

FIG. 5—TYPES OF RELAYS USED IN STEEL MILL SERVICE

These relays are for overload protection and must be thoroughly reliable in operation. The relay on the right may be reset either electrically or by hand while that on the left is reset automatically.

line makes failure of operation, due to grounded power circuits, impossible.

The master switch consists of two switches mounted together, and is arranged to open or close both sides of the control circuit simultaneously, so that grounds on the control circuit cannot possibly affect the operation. Similar double master switches are used with lift table and blast furnace skip hoist controllers, on which applications a grounded control circuit might cause the equipment to be wrecked by making it impossible to disconnect the motors from the power circuit.

Operation of the Controller—When the master switch is in the "off" position, the back contacts *2-A* and *1-A* are closed. By throwing the master switch to the "forward" position, the line switch *9* is closed and the coil of the double-pole reversing switch *1-4* is energized, closing the switch and opening the back contact *1-A* at the same time. This operation starts the motors in the forward direction. After the starting current has fallen to a predetermined value, the series lockout switch *7* closes, and thereby short-circuits a portion of the starting resistance and cuts into circuit the operating coil *OC-8* of the series "lockout" switch *8*. This causes the motors to accelerate. When the starting current has again fallen to the proper value *8* closes and, in so doing, short-circuits all of the resistance and the operating coil of *7*, and at the same time cuts into circuit its holding coil *HC-8*.

In order to stop the motors, the master switch is thrown to the "off" position. This operation de-

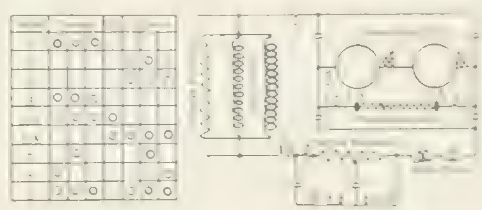

FIG. 6—SCHEMATIC DIAGRAM [illegible] SWITCHES FOR TWO [illegible] IN SERIES

OL=Over-load relay. *OC*=Operating coil. *MC*=Holding coil.

energizes the coils of all the switches and closes the back contact *1-A*, the back contact *2-A* being already closed. When this occurs the braking resistance is thrown directly across the armatures, and as the shunt fields are on the line, dynamic braking is automatically effected. Thus, the simple operation of throwing the master switch from the "forward" to the "off" position, brings the motors to a dead stop almost instantly. The same conditions hold true for the reverse direction of rotation.

The use of dynamic braking with screw-down controllers greatly simplifies the operation of the equipment and enables the operator to control the movement of the rolls much more accurately and quickly than if the usual arrangement of "plugging" or reversing the armature, in order to stop the motor, is used. The operation of the controller is so simple that no particular skill on the part of the operator is required to produce good results.

Other applications in steel mills are equally severe and as exacting on the controller and motor equipment. The reversing tables of a two-high re-

versing mill may be mentioned. These tables, one on each side of the main rolls, perform the function of returning the ingot to the rolls for the return pass, and operate about one-half as often as the screw-down. The tables are in reality a set of small rollers, geared together. Some idea of this service may be

FIG. 7—AN INSTALLATION OF ALTERNATING-CURRENT MAGNET SWITCHES CONTROLLING THE SECONDARY OF A HOIST MOTOR

gained when it is stated that the tables must receive the ingot weighing 2 to 2.5 tons coming from the rolls with a velocity of 400 to 700 feet per minute, stop, reverse, accelerate it in the reverse direction and return it to the rolls for the next pass in about two seconds. When it is further noted that a table is generally made up of 22 rollers, weighing 1 000 pounds each, the task set for the motors, and more particularly the controller can be appreciated.

The lifting and lowering tables of a three-high, non-reversing mill form another application that might be mentioned, as they illustrate best the necessity of accurate stopping, in addition to the service features. These tables perform the functions of the reversing tables of the two-high reversing mill, and in addition raise the ingot from the lower pass to the top pass, and vice versa. Motors of the slow-speed type on this latter service start, accelerate, slow-down and stop sometimes in less than three revolutions of the armature, and the stop must be accurate, as a drift of three or four inches will cause the ingot, which, as explained above, is traveling at high velocity, to wreck the table, delaying the mill for hours or even days.

An application with which most readers are familiar is the hoist movement on cranes. In steel mills before the adoption of magnetic control, it was recognized that this application was inseparable from high maintenance costs, very frequent inspections and numerous accidents. Today the magnetic control, with its advantages of ease of operation, full protection against no voltage and extreme overloads, automatic acceleration, and dynamic braking, has greatly reduced repair costs, requires no special attention and accidents are minimized so far as careless operation of the motor is concerned, and better and more efficient operation of the cranes is obtained. The use of dynamic braking in conjunction with an electric holding brake has done much to simplify the design of cranes and reduce the cost of maintenance, which was excessive with the use of mechanical brakes. It has been said by the superintendent of one of the largest steel plants, speaking of his experience with magnetic controllers, that "the use of dynamic braking hoist controllers with the elimination of mechanical brakes has at once done away with at least one-half of the troubles with cranes."

This is also true of the charging machines in the open-hearth department, the strippers in the mill, the ore bridges in the yard and the charging larries and pushers in the coke plant. When the universal use of cranes is borne in mind—especially in steel mills, where they are used to handle the raw materials, the finished steel and also the hot metal in liquid and in solid form, in handling which an accident may not only mean delay with great expense, but also frightful loss of human life—the value of the improvement in service, as effected by magnetic controllers, can be better appreciated.

To meet the conditions of mill service successfully, every part of the controller must be developed to give the highest type of service. The success of the controller is dependent not only upon the working relation of the various parts, but also, and to a large extent upon the ability of each part to stand up under the conditions imposed upon it. Too often, too much attention is paid to the wiring diagram or some other abstract feature of the control system in the selection of controllers. A controller is reliable only so far as every part of it is reliable.

With the introduction of magnetic control, amid the enthusiasm aroused by its apparent advantages over manually-operated controllers, the necessity of making the detail parts equal to the service conditions was overlooked. As a result, some of the designs brought out by manufacturers in the early development were inadequate for the conditions to be met. As an example, the earlier types of master switches were weak and flimsy, being simply a means of making the necessary connections, with no provision to meet unusual conditions, resulting from abuse, accidents, mill dust, etc. The later master switches have

FIG. 8—DETAIL PARTS INTERCHANGEABLE BETWEEN DIRECT AND ALTERNATING-CURRENT MAGNET SWITCHES OF CORRESPONDING RATINGS

proved reliable and durable in mill service. These same features are also exemplified in the relays shown in Fig. 5. Controllers that meet the conditions as noted above successfully and reliably are only made possible by rugged design of all parts with simplicity as the keynote of the systems, eliminating small parts as much as possible.

The successful development of magnetic control has been one of the prime features in widening the scope of motor drive. Particularly has this been true of the recent development of the alternating-current magnet switch together with the corresponding relays. This has been retarded somewhat due to the difficulties presented by the inherent characteristics of alternating-current magnets; at present, however, its application has been successful in a considerable variety of applications, one of which is illustrated in Fig. 8.

The alternating-current switch is simple in construction and thoroughly reliable in operation, its design being based on the success of the direct-current switch. In fact many of the details of the latter are interchangeable with the corresponding parts of the alternating-current switch of the same rating; thus reducing the number of parts necessary for stock where both switches are used in the same mill.

Electric Elevator Control

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TEN YEARS ago the electric elevator was used for the most part on small installations. The large office buildings and hotels used hydraulic power to operate their elevators. The hydraulic elevator, however, has the disadvantage that it is inherently a constant power machine, as it takes the same amount of water whether the car is operated empty or loaded; and, further, it is not feasible to over-balance the car, as the hydraulic elevator is essentially a single-acting machine and a part of the car weight must be left unbalanced in order to circulate the water when the car is descending. There is the added disadvantage that every hydraulic installation requires a power plant consisting of pumps, tanks, regulating apparatus and a considerable amount of expensive piping. Accordingly, although many large installations still use hydraulic elevators, the recent improvements in electric elevators have extended their usefulness to such an extent that today they are direct competitors of the hydraulic elevator on all large installations; in fact, some of the highest buildings have been equipped with electric elevators because it did not seem feasible to use hydraulic elevators for such heights.

H. D. JAMES

The electric elevator has less investment and maintenance cost than the hydraulic, due to the elimination of the power plant, and is also more economical in that the power used is not a constant quantity, but is in proportion to the load. However, there still exists some difference of opinion as to the relative costs of the electric and the hydraulic elevator, for particular installations; but the fact that the electric elevator is today successfully competing with the hydraulic elevator in the latter's main strongholds—the large office buildings and hotels—makes it an important feature in the sale of central station power, as in large cities the electric elevator is an important factor in smoothing out the load curve of the central station.

An important part of every installation is the controller which must accelerate and retard the car smoothly and bring it to rest either at the will of the operator or automatically in case of accident to the control or hoisting mechanism.

Every direct-current controller must have the following parts:—

1—A line switch to disconnect the motor from the electric circuit. This switch may be operated every time the car is operated, or it may remain closed normally and be opened only by some of the safety devices or when the line voltage fails.

2—A reversing switch to change the direction of rotation of the motor. (Sometimes several switches are used combining *1* and *2*.)

3—An accelerating device for gradually short-circuiting the starting resistance. Where a variable speed direct-current motor is used, this device must also gradually weaken the motor field to attain the maximum speed of the elevator car.

4—A dynamic brake for slowing down the car when the elevator is brought to rest. This device is sometimes omitted in slow-speed freight service.

5—A mechanical brake for stopping the elevator car and holding it securely at the landing.

6—A top and bottom limit stop for bringing the car gradually to rest at either limit of travel, independently of the operator.

7—A controlling device in the car for operating the elevator. This may consist of a master switch or a mechanical device such as a rope or a lever.

8—A slack cable device for stopping the motor in case the car or counter-weight should become obstructed in its travel, causing the ropes to lose their tension. This does not apply to the traction type of elevators.

9—An over-speed switch for disconnecting the motor from the line at the time that the car safety device operates to grip the guide rails. In some forms of machine a slack cable switch is depended upon to perform this operation.

10—Overload protection to the motor. This frequently consists of fuses, although sometimes overload and no-voltage circuit breakers are used, or a circuit breaker relay with magnet control.

In addition to the above, high-speed passenger elevators must have the following control features:—

11—One or more positive slow-speed notches. It is necessary to have a slow-speed notch to enable the operator to stop his car accurately at the landings. This slow speed is also necessary to bring the car to rest properly at either limit of travel. Where the speed of the car exceeds 400 feet per minute, several slow speeds are desirable in order to obtain efficient operation of the elevator.

12—An emergency switch on the car to enable the operator to stop the car in case his regular controlling device becomes disarranged.

For high-speed elevators, it is customary to provide oil-buffers under the car and counter-weights; also a mechanical brake on the car by which the slide rails are gripped to retard the car in an emergency. This brake usually is an attachment to the regular safety stop. In addition to the controller proper, it is desirable to provide contacts on the hatchway doors or gates which will prevent car operation until the gate is closed. Sometimes the car itself is equipped with a gate having one of these contacts.

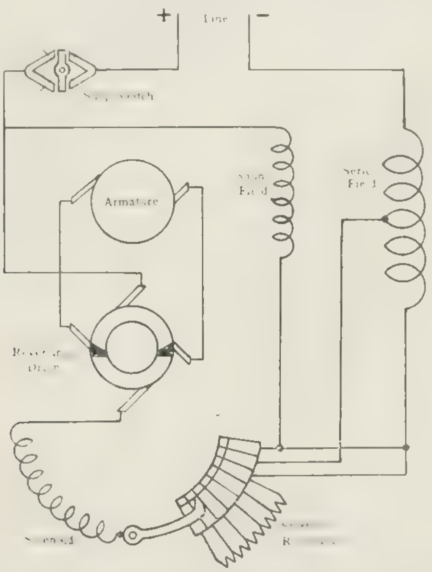

FIG. 1—EARLY TYPE OF CONTROLLER FOR DIRECT-CURRENT ELEVATOR MOTORS

The above functions of the electric control are accomplished in a variety of ways, the devices used depending largely upon the characteristics of the electric motor.

DIRECT-CURRENT ELEVATORS

The first successful electric elevators were operated by compound-wound direct-current motors, These motors had a fixed shunt field; the compound winding was cut out after starting so that the motor operated as a shunt motor at full speed. This design gave a good starting torque, together with good speed regulation after full speed was reached. Fig. 1 shows a diagram of one of the earlier controllers. The reversing drum was operated first, being followed immediately by the closing of the line switch, which was of the quick-break type; next the resistance arm was released, moving the brush over a series of contacts which short-circuited the starting resistance and afterwards the series turns on the motor field. The resistance arm was raised by a series wound solenoid and retarded by a dash-pot. This form of controller with various mechanical modifications, is used successfully today for slow-speed passenger and freight service.

The first of the subsequent developments were improvements in the method of cutting out the starting resistance. Some controllers used a shunt coil connected across the motor terminals and actuated by the counter e.m.f. of the motor for moving the resistance arm shown in Fig. 1. This same arrangement is now used, except that the resistance is short-circuited by individual switches actuated by the counter e.m.f. of the motor and the dash-pot is omitted. Other arrangements were developed for closing these individual resistance switches, depending upon the amount of current taken by the motor. The dash-pot method of acceleration has one distinct advantage, namely,—the resistance can be proportioned to start the motor under light load; the accelerating device will continue to reduce this resistance until the car starts even under heavy load, so that it is very seldom that an elevator having this method of acceleration will fail to start. This advantage has caused many manufacturers to retain the use of the dash-pot, although there are some troubles inherent in this type of apparatus.

Another improvement has been in the line switch and reversing switch. The line switch, Fig. 1, has been replaced in most controllers by an electrically-operated switch. Sometimes several of these switches are used for reversing the motor, while in other cases a mechanical reverse switch in combination with an electrically-operated line switch is found to be cheaper and just as satisfactory for slow-speed service. A number of other devices for accelerating the motor have been tried, but are seldom used at present. One such device was a rheostat driven by a pilot motor. In addition to the expense of this device, it was too slow in returning to the starting position.

With the development of the shunt motor with a two to one speed adjustment, a new feature was introduced in elevator control. This motor gave two fixed running speeds and made the control of high-speed elevators more positive. Trouble was experienced at first in changing from maximum to minimum speed and vice versa. When the field was reduced the motor had a tendency to jerk the car and take a heavy current; when the field was strengthened, the motor acted as a generator and reversed the direction of current, tending also to jerk the car. The best method for controlling the field of the shunt motor is the so-called "fluttering" relay, which strengthens the shunt field on an excess of current, and reduces the field by inserting resistance when the current drops to the proper value.

A further increase in car speeds made it necessary to provide a slower running speed than could be economically obtained by shunt field control. This slow speed is secured by shunting the armature with

a resistance at the same time that resistance is inserted in series with the armature, as shown diagrammatically in Fig. 2. This diagram is arranged for a complete magnetic controller having several speeds in each direction of operation. The point *BK* is in effect only when stopping. In starting, the master controller is turned directly from the off position to *1*, *2* and *3*, as indicated, the second point automatically cutting out the series field resistance and then the series field itself. The field relays FR_3 and FR_4 are in operation only in the first and second positions, the fluttering relay FR_2 regulating the shunt field in the third or high speed position. A view of the controller is given in Fig. 3.

The method of operating the car at first consisted of a mechanical device, either a rope, a wheel or a lever, connected through the proper gearing to the controller. Devices of this kind are still in use on freight and slow-speed passenger elevators. The modern elevator, particularly for high speeds, is provided with a master switch in the car, so arranged that it is returned to the central or off position if the operator releases the handle. In addition, a safety switch is usually provided to stop the car in case of accident to the master switch.

In private residences, hospitals and other places where the elevator is not used enough to warrant the expense of a regular operator, the push button system of control is used. This is an elaborated form of master switch. Each landing is provided with a push button to bring the car to that landing, and a set of push buttons is located in the car for dispatching it to a predetermined landing. These push buttons operate a selecting circuit which is opened by mechanical means when the car reaches that particular landing. A cam on the car unlocks the door when the landing is reached, and the opening of the door breaks the control circuit so the car cannot be started until the door is again closed. A safety button is provided in the car for stopping the car at the will of the passenger. Many of these devices are in successful operation. They first began to meet with favor about 15 years ago. As far back as 1887, devices of this kind were applied to hydraulic elevators, the valves of which were controlled by electro-magnets.

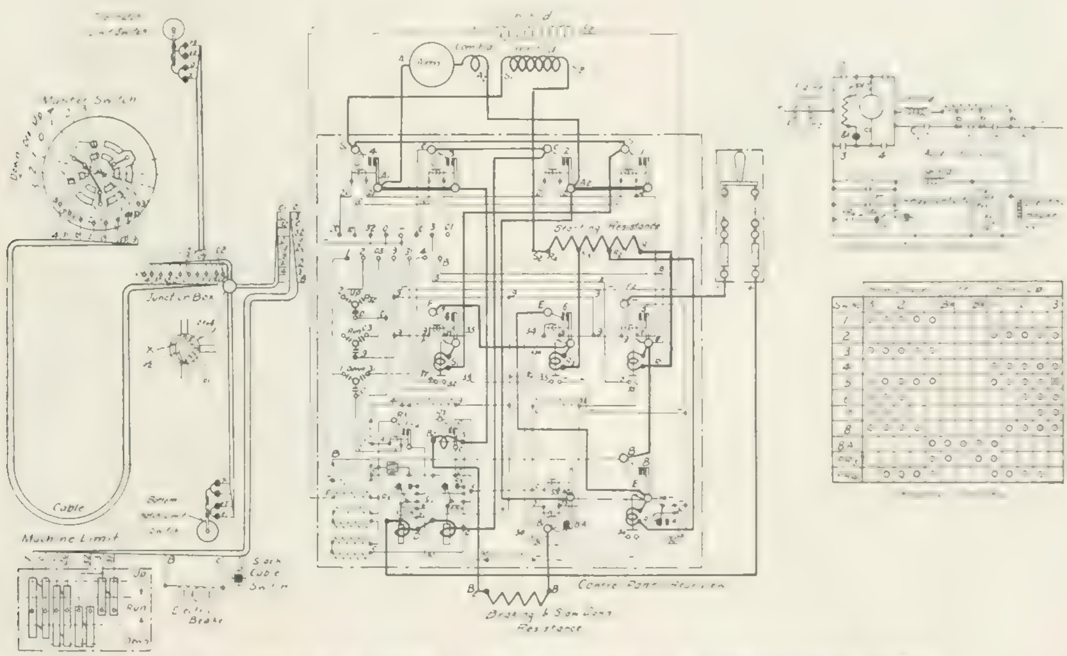

FIG. 2—DIAGRAM OF OPERATION FOR A MODERN HIGH SPEED [illegible]

Master switch motion may be reversed by interchanging leads *1* and *2*, *31* and *32*. If door switches are used, they are to be connected in the *X* wire between the bottom and top hatchway limit switches and not in the *02* wire.

ALTERNATING-CURRENT ELEVATORS

About 1897, the alternating-current motor commenced to be a factor in the operation of elevators. These motors are of two types—the squirrel-cage and the slip-ring. The squirrel-cage motor is started and controlled merely by closing the primary switch, no external resistance being used. In small sizes, this motor presented no difficulties, but in sizes over five horse-power the early motors took so much current at starting that they caused serious disturbance to the power supply. At that time, very few central stations had sufficient line capacity for starting these large size motors. The slip-ring motors were more common in the larger sizes. They had external resistance in the secondary circuit. This resistance was short-circuited during acceleration by means of a mechanical switch controlled by a dash-pot. They were fairly successful for car speeds of 150 to 200 feet, but could not be used at higher speeds. They also gave trouble due to the large amount of stored energy in their rotating elements. As the problem of induction motors for elevators became better understood by motor designers, a better type of induction motor was developed for elevator service. This motor had a long rotating element of small diameter, giving a minimum stored energy and having an electric design well adap-

ted for heavy starting torque. The squirrel-cage motor of this type, illustrated in Fig. 4, is designed to develop its maximum torque at starting, and takes a comparatively small current when it is first started. It is generally used in preference to the slip-ring type

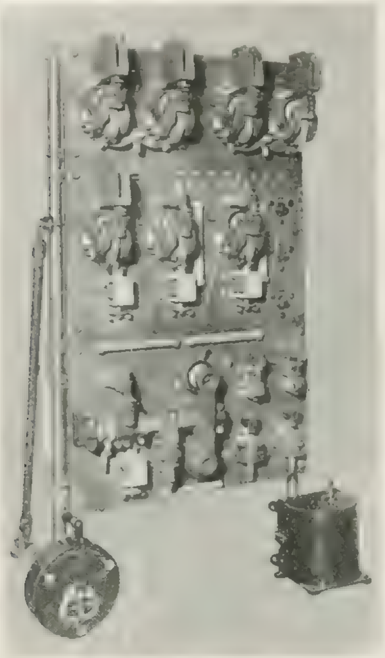

FIG. 3—DIRECT-CURRENT ELEVATOR CONTROLLER

The master switch for mounting inside the car is shown at the left in the foreground. This is the controller shown diagrammatically in Fig. 2.

up to the 20 horse-power size, although a number of slip-ring motors are used in small sizes where the power supply is limited. Larger motors of the same general design arranged with slip rings for external resistance at starting are also used. The control of these motors is usually mechanically operated, the ac-

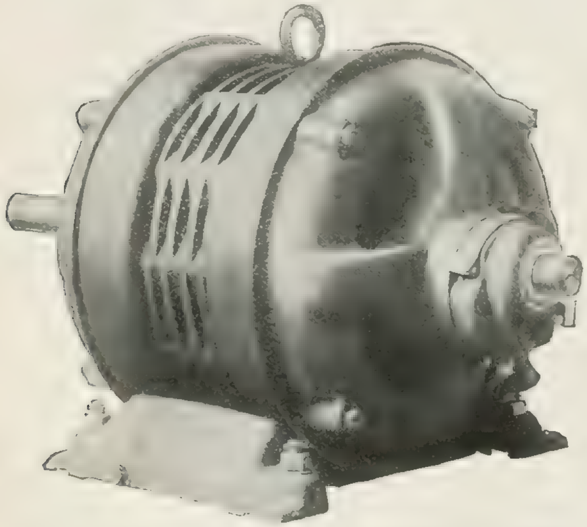

FIG. 4—MODERN WESTINGHOUSE ALTERNATING-CURRENT ELEVATOR MOTOR

celeration being controlled by a dash-pot. Fig. 5 illustrates a typical control of this type. Recently, magnet switches with current-limit acceleration have been used for such motors. The great difficulty experienced with this form of controller is to keep the switches quiet, the alternating-current in the magnet winding causing the switches to hum or rattle which, in some cases, is objectionable.

The latest development in alternating-current elevator practice is a two-speed motor, the slow speed being one-third of the full speed. Such a motor is adapted for high-speed elevator work as the slow speed of the motor will enable the operator to control the car easily when making landings. It also permits a satisfactory top and bottom limit stop being used. The car is made to approach either limit of travel on the slow speed, so that the mechanical brake can easily stop the car when the limit of travel is reached. The control for this motor consists of a reversing switch, a pole-changing switch and an accelerating device for short-circuiting the secondary winding used in connection with the high-speed combination. The

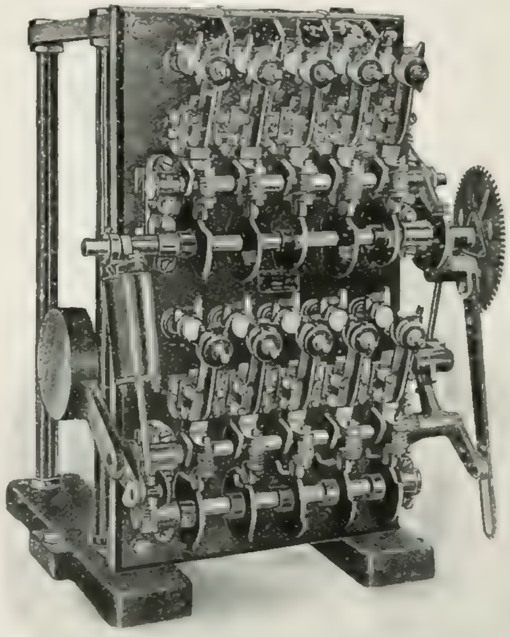

FIG. 5—A SEMI-AUTOMATIC ALTERNATING-CURRENT ELEVATOR CONTROLLER

low-speed combination has a squirrel-cage rotor. This device is a very recent development, but elevator engineers expect great things from it in the future.

The art of controlling electric motors in general owes a great deal to the elevator engineer. It was in connection with electric elevators that the first controller developments were made for the constant speed motor while the railway field developed the series motor and its control. When the attention of electrical engineers was called to the development of the electric motor for industrial purposes some 15 years ago, they turned to the elevator and railway field for their information and, because the problem had been solved so well by these engineers, it was not found difficult to apply electric motors to many other industrial requirements. Since then, the developments along many lines have gone hand in hand, so that the present electric elevator controller has been vastly improved in detail and reduced in cost.

Magnetic Controllers for Crane Motors

W. O. Lum

Industrial Control Division,
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Cranes, more than any other class of machines, are responsible for the increasing application of magnetic control to electric motors. This is due in part to the failure of manually operated controllers satisfactorily to handle motors of over 25 horse-power in severe service, and in part, perhaps mostly, to the increased safety and lower maintenance cost for magnetic controllers in severe service with large motors. Although more apparatus is required for the magnetic controllers than for the manually operated types, the elements that comprise the complete controller are relatively few so that the number of different parts that have to be mastered is not excessive. The wiring is much simpler to understand when the idea of treating each magnetic device as a simple switch, with magnets to operate it, is once fixed in mind.

W. O. LUM

Magnetic controllers practically eliminate the possibility of abusing a crane. The rate of acceleration, the value of dynamic braking and the value of reversed torque in "plugging" are all controlled by automatic devices that may be set at any desired point, not by the operator, but by an authorized attendant whose interest lies in continuous operation. Also the limits of travel are easily arranged so that it is impossible for the operator to overtravel any of the motions under his control.

Probably the one application that marks the greatest advance in this line is that of the controller for ladle cranes in steel mills. These cranes often consist of three separate trolleys and hoists on one bridge and handle burdens of molten steel as large as 100 tons. This 100-ton burden has a most innocent and harmless appearance when resting quietly in a suspended ladle, but if for any reason the hoisting apparatus should fail, either from a broken cable (which seldom if ever happens now) or from a slipping brake or defective controller, the steel is spilled, resulting not only in the loss of steel and apparatus but usually in the serious injury of any men who happen to be near. It will readily be understood that nothing but the very best apparatus is permitted to be installed on such cranes.

The hoist motion on ladle and hot-metal cranes of large size is usually operated by two motors—connected permanently in multiple. Some applications have been made with series-multiple connections, but in every case that has come under the writer's observation the range of speed that is available with the multiple connection is entirely adequate for all needs. In extreme cases extra slow speeds may be obtained by additional shunts around the armature. It is good practice when two motors are connected in multiple and geared to the same machine to apply a complete controller for each motor. With this arrangement no trouble is experienced with unbalancing of the load between the motors, and one motor may easily be cut out of circuit in case of emergency without in any way affecting the operation of the other.

The range of speed that is possible on a series motor may be from five percent of normal full-load speed at full-load torque to 25 percent over full-load speed at full-load torque. This range can be accomplished by shunting the armature with resistance for the slow speeds and shunting the field with resistance for the high speeds. This of course is in the hoisting direction only. In the lowering direction it is necessary to change the series motor to a shunt motor so that it will not overspeed on an overrunning load. This is done by connecting the series field across the line in series with a resistance and controlling both the field and the armature in the way common to shunt motors. The brake magnets should be in series with the field so that should the field fail the brakes will set, and also to prevent the brakes from setting when the armature current passes through zero.

Magnetic controllers arranged to give connections as described above are also easily arranged to give dynamic braking connections in the off position of the controller and upon failure of voltage or occurrence of overload. The accompanying illustrations give an excellent idea as to the degree of simplicity to which these devices have been reduced. Overspeed and overtravel limits are easily provided which work in conjunction with the magnetic control so that the motors will be stopped in case of excessive speed or excessive travel.

The controllers for the motors on the bridge motion of ladle cranes must be arranged so that small increments of motion are readily attainable and they must also be arranged so that the highest speed of the motors may be obtained for long runs. Usually two motors are used in operating the bridge motion and it is ordinarily assumed that series-parallel operation of these motors will result in maximum efficiency. As a matter of fact, the writer has observed that the series connection in this application is entirely unnecessary, and in cases where controllers were sup-

plied to give either series or parallel operation on the motors that the series position is not used by the operator. Cranemen performing the same duty with the same machine day after day become expert in handling these machines and the common method used by cranemen in spotting the ladle over the ingot molds is to place the controller on a high speed position, starting the bridge up rapidly; the ladle suspended 30 or 40 feet below the trolley acts as a huge pendulum and does not follow the motion of the bridge instantly. The operator stops the bridge a trifle short of the distance to the next mold and allows the ladle to swing over the mold. At the instant the ladle is over the mold the bridge is again started in the direction the ladle is swinging and stopped again just as the ladle comes to rest over the mold. Although this operation sounds difficult when described, it is easily understood when witnessed. In cases where extreme speeds for long runs are required, it is quite possible to shunt the series fields of the operating motors in order to get higher running speeds. This probably is more desirable than resorting to series-parallel control.

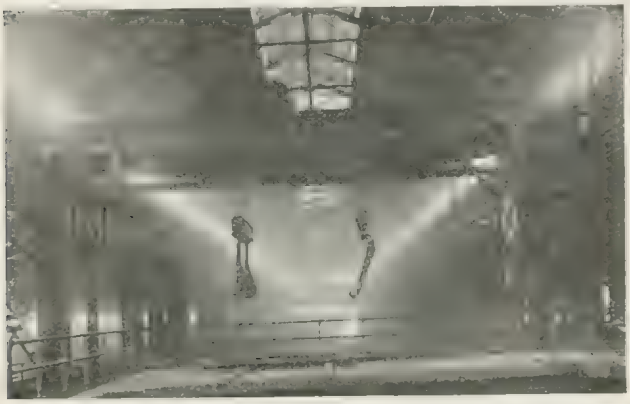

FIG. 1—A 100-TON LADLE CRANE AT THE PLANT OF THE BRIAR HILL STEEL COMPANY

Showing main and auxiliary cabs. Motors are controlled from either cab.

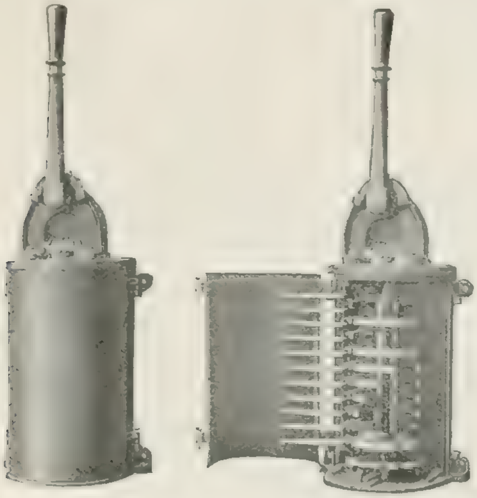

FIG. 2—DRUM-TYPE MASTER CONTROLLER USED IN CRANE SERVICE

The arc shield is hinged to swing clear for inspection.

The trolley motion of these large cranes may be dealt with in exactly the same manner as the bridge motion excepting, of course, that the motors are much smaller and there is no reason for extreme ranges of speed. It is well understood by those who have had experience, that motors operating traction machines must necessarily be handled differently from motors that are operating other types of machines where the torque required to start the load is approximately constant. With traction machines, especially when "plugging" control is used, it is necessary to provide

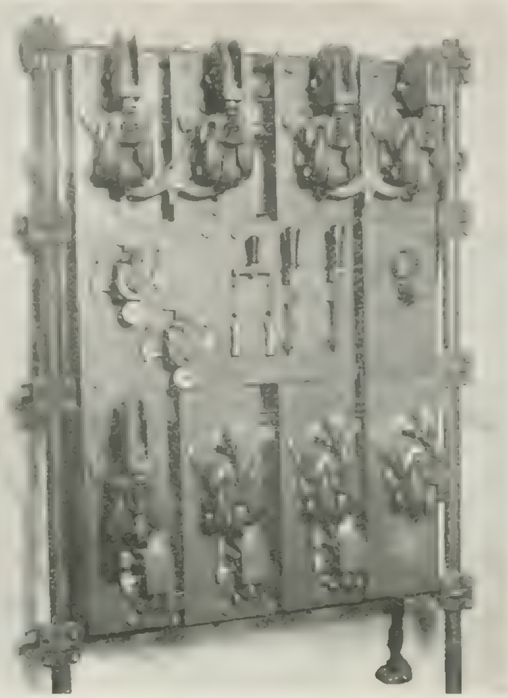

FIG. 3—CONTROLLER FOR A 75 HORSE-POWER BRIDGE MOTION MOTOR

Equipped with double overload protection, no-voltage protection and current limit acceleration. This control furnishes four speeds forward and four reverse.

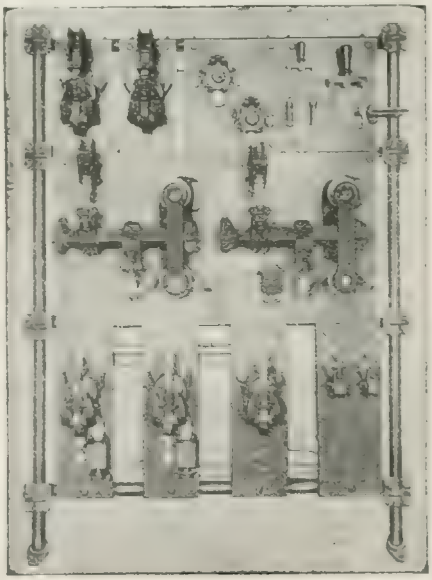

FIG. 4—HOIST MOTION CONTROLLER FOR 75 HORSE-POWER MOTOR

This controller gives five different speeds, both hoisting and lowering, and is provided with double overload protection and no voltage protection. Acceleration is by current limit for both hoisting and lowering.

more accelerating points than with other types of machines, in order to keep the motor current well within the limits of the tractive effect at the wheels. It must be remembered that with "plugging" controllers on bridge motions, excessive current to the motor at the instant of "plugging" will skid the wheels and if this occurs near the limits of travel a wreck is liable to occur. The current must, therefore, be positively limited on the first point, so that when throwing from full speed in one direction to full speed in the reverse direction the motor torque will not exceed the tractive effect at the wheels.

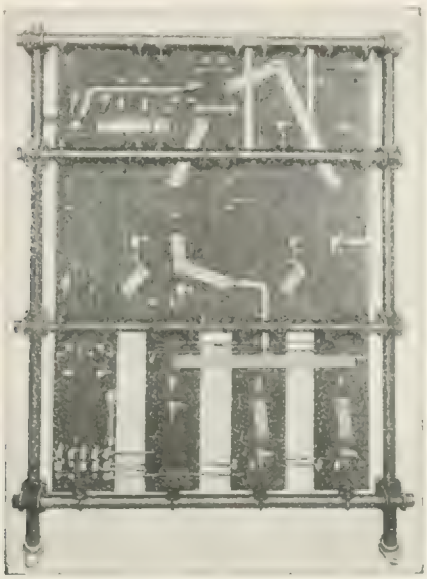

FIG. 5—REAR VIEW OF THE CONTROLLER SHOWN IN FIG. 4
Showing simplicity of wiring layout and connections.

None of the motors on a ladle crane is larger than 25 horse-power and some of them do not get the severe service that the main hoist and main bridge motors receive. Therefore, a combination of manual control and magnetic control is often used on a single crane. In order to provide overload and no-voltage protection for the manually operated controllers on the crane, a "crane protective panel" is used. Upon this panel is mounted a knife switch through which all of the manually operated controllers are supplied; one or two magnetic switches in series with this knife switch and arranged with no-voltage protection; one overload relay in the common line; and one overload relay in one side of each motor circuit. These overload relays open the magnetic switches in case of an overload on any one motor or in case of accumulative load which exceeds the capacity of the outfit.

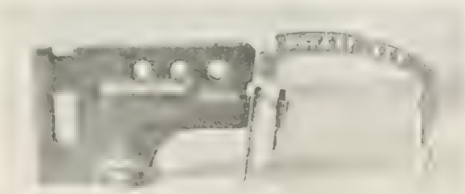

FIG. 8—SAFETY LOCK USED WITH KNIFE SWITCHES
After the key is removed padlocks may be inserted in the holes.

After an overload or failure of line voltage, it is necessary for the operator to press a push button which resets the magnetic switch before the motors operating through the protective panel can be started.

Although reference is made more particularly to ladle cranes, the same rules apply in varying degree to other applications. It happens that the ladle crane presents the most exacting requirements and therefore is used as an example.

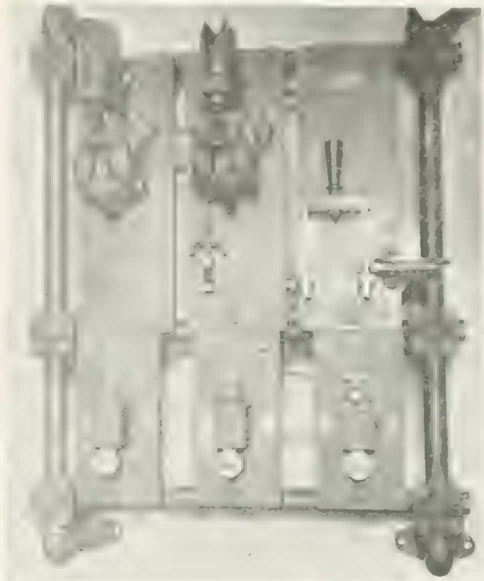

FIG. 7—CRANE PROTECTIVE PANEL
This panel covers two motors. The knife switch is provided with a safety lock such as shown in Fig. 8.

The question of whether or not magnetic control should be used on any given installation should be determined not by the size of the motor alone, but by the nature of the service to which the outfit is to be subjected. If the service is severe, that is, if the crane is in constant use there is no doubt but that magnetic control will soon pay for itself in time saving and repairs. On the other hand, if the service is very infrequent, there is no reason why manually-operated controllers cannot be used successfully on motors up to and including 25 horse-power.

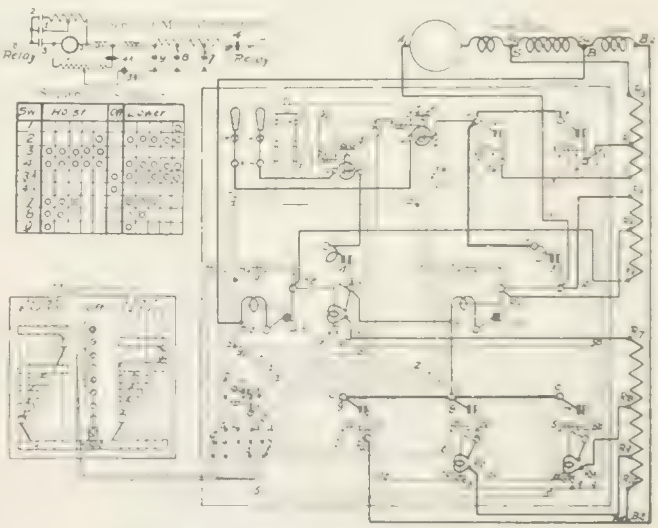

FIG. 6—DIAGRAM SHOWING CONNECTIONS AND SEQUENCE OF OPERATIONS OF A CRANE-HOIST CONTROLLER

Liquid Rheostats

FOR CONTROLLING WOUND-SECONDARY INDUCTION MOTORS

W. E. Thau

General Engineering Department, Westinghouse Electric & Mfg. Company

THERE are in use at the present time two principal types of liquid rheostats for controlling wound-secondary induction motors; one is designed for severe service and is reversing, the other is designed for light and infrequent starting duty only and is non-reversing. In the former type the electrolyte is pumped into a chamber containing stationary electrodes, while in the latter the electrodes are revolved into a chamber containing the electrolyte. The former type is designated herein as the *heavy duty type* and the latter as the *light duty type*. The heavy duty type is applied principally in mine hoisting, haulages, dredges, etc., where the service is severe and the starting frequent. The light duty type is applied on motors driving fans, centrifugal pumps, etc., where the service is not so severe and the starting is infrequent. This type may be arranged for automatic remote control, or may be hand operated.

W. E. THAU

HEAVY DUTY TYPE

A schematic sketch of the heavy duty type is shown in Fig. 1. The case is built of rolled steel plate and arranged into upper and lower compartments. The electrolyte, consisting of ordinary sodium carbonate solution, is pumped from the lower compartment, which serves as a reservoir, into the upper compartment, containing the electrodes, by means of a motor-driven centrifugal pump. Cooling coils, through which cooling water is passed, are provided in the lower compartment. A movable weir, actuated by means of a system of levers, regulates the level of the electrolyte in the upper compartment. Both ends of this weir are open and when lowered the electrolyte rapidly flows through into the lower compartment. The liquid pressure is equal on all sides and there is, therefore, practically no side friction to hinder the movement. To compensate for the weight of the weir and its supporting levers, a counterweight is provided. A master switch, which controls the primary reversing switches, is operated through gearing by the lower lever. The lever system of the rheostat is operated by means of a rod connected to the operating lever and controlled by the operator. A valve mounted in the electrolyte discharge pipe provides a means of regulating the rate of flow of the electrolyte into the upper chamber.

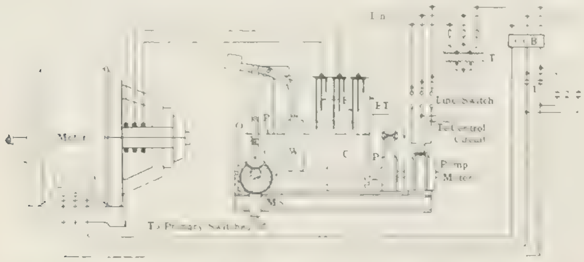

FIG. 1—SCHEMATIC DIAGRAM OF HEAVY DUTY TYPE LIQUID CONTROLLER

R—reservoir; *ET*—electrode tank; *E*—electrodes; *W*—weir; *CC*—cooling coils; *O*—point of attachment of rod from operating lever; *P*—pump; *V*—regulating valve; *MS*—master switch; *OCB*—oil circuit breaker; *T*—transformer; 1 and 2—reversing switches.

The electrodes are made of corrosion-resisting iron plates, supported by heavy steel rods, which are secured at the ends of bakelite-micarta insulators. The plates of like phase are spaced by means of steel rods and held by lock nuts. The heavy duty type of liquid rheostat is shown in Fig. 2.

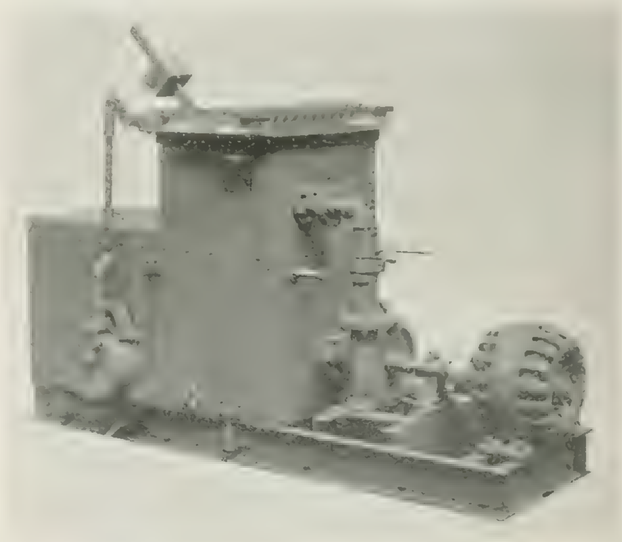

FIG. 2—LIQUID RHEOSTAT FOR HEAVY DUTY

OPERATION

The operating lever controls both the master switch and the weir. When the lever is in the central or "off" position, the electrically-operated primary directional switches are open and the weir is at its lowest level, so that the secondary resistance is a maximum. Moving the lever in the "forward" direction closes the proper primary switch and raises the weir. The lever may be moved immediately to the "full-on" position, in which case the electrolyte will rise at a rate determined by the setting of the regulating valve.

The reverse direction of operation is effected in a similar manner, the leads being reversed by magnet-operated switches.

The regulating valve in the discharge pipe regulates the flow of the electrolyte into the upper chamber, so that no matter how quickly the lever is moved to the "full-on" position, the electrolyte can rise only at the rate for which the valve is adjusted, thus fixing the rate of acceleration of the motor and relieving the operator of the responsibility. The rheostat can be designed to fill in from five to twenty seconds and empty in two seconds without splashing. When the lever is returned to the "off" position the primary switch opens and the weir drops, allowing the electrolyte level to promptly fall.

The pump for the electrolyte operates continuously so that cooled liquid is continually passing into the upper chamber. The rheostat has large capacity so that there is no danger of the liquid boiling and thereby wasting away rapidly by evaporation. Ample cooling coils provide a means of disposing quickly and

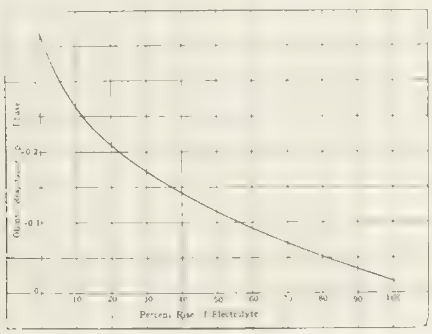

FIG. 3—CURVE SHOWING THE RELATION BETWEEN THE HEIGHT OF THE ELECTROLYTE AND THE RESISTANCE IN A LIQUID RHEOSTAT WITH A THREE PERCENT SODIUM CARBONATE SOLUTION

positively of the energy dissipated in the liquid resistance as heat.

ADVANTAGES AND SALIENT FEATURES

The advantages of the liquid rheostat over the magnetic type of controller and any other type using metallic resistance are,—smooth acceleration, low maintenance, simplicity of repairs and simplicity of operation.

The electrode plates are cut at an angle at the bottom and are of different lengths so that, as the liquid rises, the change in resistance takes place gradually. The lower ends of the longest plates are always submerged in the electrolyte and are so shaped that a high resistance exists between the phases, thus insuring a high starting torque. As the liquid rises the value of the resistance decreases gradually and approaches zero when the liquid has attained its maximum height. A resistance curve taken from an actual test on one of the smaller rheostats is shown in Fig. 3. In the larger sizes an extra switch is sometimes supplied for entirely short-circuiting the rheostat after the motor has reached full speed. However, this switch is ordinarily unnecessary. The ohmic resistance of the solution can be varied by changing the percentage of salt dissolved.

Any type of control using metallic resistors produces a more or less peaked input curve and consequent sudden increases in the speed, due to the cutting out of comparatively large groups of resistance at one

FIG. 4—LIGHT DUTY TYPE OF LIQUID RHEOSTAT

time. The magnitude of these peaks and the severity of the speed changes depend upon the number of the starting steps. In hoisting and haulage service where loads having large inertia are started through the medium of ropes, these sudden starting peaks produce objectionable strains in the ropes. The smooth accelerating curve of the liquid rheostat, being the equivalent of an infinite number of switches, overcomes this objectionable feature of the metallic resistor.

The parts of the liquid rheostat are simple in construction, substantially proportioned and conveniently arranged. Due to the small number of parts, there is little to get out of order and, when repairs are needed, they can be made by an ordinary mechanic, and the maintenance is therefore low. There are no arcing tips to be renewed and no metallic resistances to be burnt out by careless handling. The only parts which need renewing are the electrolyte and the electrodes. The

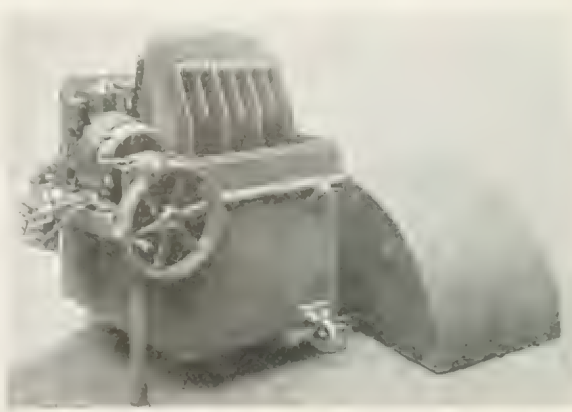

FIG. 5—OPEN VIEW OF RHEOSTAT SHOWN IN FIG. 4

former can readily be mixed and added as needed. The evaporation of the electrolyte under severe conditions seldom exceeds a gallon a day in the medium sizes. The plates, due to electrolytic action, require renewing about once a year. They are mounted in complete

units so that replacing is a very simple matter. In addition to these advantages, the principle of operation is so simple that an inexperienced operator can readily obtain good results.

It is often necessary to operate a hoist at slow speed in order to inspect the shaft and rope, and in this respect the liquid rheostat is well adapted owing to its large cooling capacity which is required to dissipate the heat caused by continuous running at reduced speeds. In this connection, it is well to note that, due to the inherent speed-torque characteristic of the induction motor, it is necessary to have the cage loaded in order to maintain the slow speed, since at light loads the induction motor approaches synchronous speed regardless of the secondary resistance.

LIGHT DUTY TYPE

In this type of liquid rheostat the electrolyte is contained in a tank built of rolled steel plates. Corrosion-resisting iron-plate electrodes are mounted on a shaft, which is either motor or hand-operated through a set of gears, and revolve into the electrolyte. Due to the light service and infrequent starting, it is not necessary to provide cooling coils. Views of a motor-operated light duty liquid rheostat are shown in Figs. 4 and 5.

When a liquid rheostat is motor-operated, the operating motor is usually controlled from a remote point, in which case a controlling relay switch is arranged so as to start the motor upon the return of voltage. The auxiliary control circuit is so arranged that after the voltage has been interrupted the plates must be revolved to the "off" position before the main motor primary switch can be closed. This provision, which is automatic, prevents the connecting of the main motor directly to the line with the plates fully submerged. The automatically-operated type is particularly applicable in the case of motors driving fans in mines, where it is desired to have the fan operate continuously and the starting automatic. The plates of this type also are so shaped so as to produce a smooth accelerating curve. The advantages offered are similar to those mentioned for the heavy duty type, except that is is not suitable for continuous running at reduced speeds, except for short intervals.

A very important advantage of the liquid starter in gaseous locations is the absence of sparking contacts in the secondary circuit, so that only the primary switch need be enclosed in flame proof casing.

Control for Electrically-Driven Rubber Calenders

T. E. SIMPERS

Industrial and Power Dept.,
Westinghouse Electric & Mfg. Company

THE rubber calender consists of three or more steel rolls, usually three, connected by gears so that they may run at the same or different speeds. These rolls are held between upright housings and the compounded rubber is forced between them. Rubber calenders are used for three general classes of work; namely, calendering or sheeting—which consists of producing sheets of rubber of the desired width and thickness for some further operation; skim coating, consisting of coating a fabric with a layer of rubber; and frictioning, which is the manufacture of friction cloth, produced by forcing rubber into the fabric. For each of these operations the speed ranges are different, as are also the power requirements. To secure maximum production from each calender, it is necessary to operate it at the maximum possible speed for the particular operation, and this will vary according to the thickness of the material and the kind of work, and is limited by the heating of the calender rolls and the tearing of the material. Therefore, the apparatus driving the calender must be capable of being varied in speed and it must also have good speed regulation to avoid producing material of uneven thickness or tearing of material. In practice, it is found that a speed range of four to one is sufficient for all classes of work and, in plants where the variety of product is limited, a much smaller range of speed is sufficient.

T. E. SIMPERS

Tests on calenders have shown that their power requirements are practically on a constant torque basis; i. e., the horse-power requirements are nearly proportional to the speed. The curve of Fig. 1 shows the test results obtained from a three-roll 18 by 36 inch calender doing calendering work. From this curve can be noted the constant torque characteristics of the work.

There are a number of systems in use for electrically driving calenders and in general the require-

ments of the control of each system may be given as follows:—

1—Overload and no-voltage protection.
2—Simple and convenient means of starting and stopping.
3—Convenient method of securing speed variation where used.
4—Quick and positive stopping of the calender when shut down.
5—Provision for reversing in emergency.

The last two features are added to provide all possible safety for workmen. In spite of guards the limbs or clothing of workmen sometime become caught between the rolls and immediate stopping may prevent serious injury. Three to five operators are required for each calender and, to provide them with all possible protection, several push-button stations are installed. Then, in case a workman is in danger, the calender may be stopped instantly by any of the operators at any station.

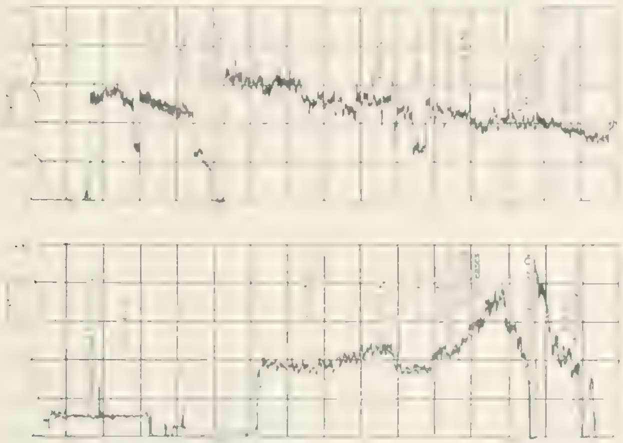

FIG. 1—LOAD CURVE OF A 50 HORSE-POWER DIRECT-CURRENT MOTOR

Driving a three-high, 18 by 36-inch roll rubber calender with a 12 by 36-inch banking roll. Motor speed 200 to 1 000 r.p.m.; on controller points 1 to 11, the motor armature is on 110 volts; on points 13 to 27, on 220 volts.

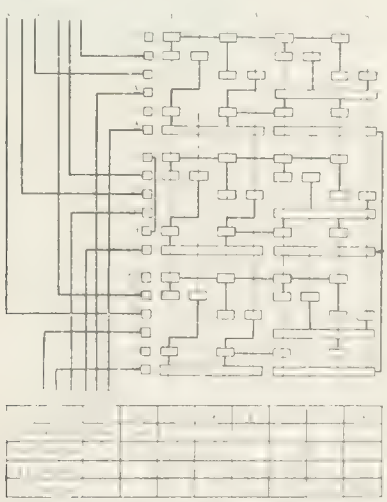

FIG. 2—CONTROLLER DIAGRAM FOR A THREE-PHASE, FOUR-SPEED SQUIRREL-CAGE INDUCTION MOTOR IN RUBBER CALENDER SERVICE

L_1—L_2—L_3 is a three-phase, 46 cycle, 340 volt line and L_4—L_5—L_6 a three-phase, 60 cycle 440 volt line. A'-B'-C' is the 16 pole connection of the motor windings and A-B-C the 8 pole.

SQUIRREL CAGE MOTOR DRIVE

The simplest method of operating a rubber calender is by the ordinary squirrel-cage motor operating on an alternating-current circuit, in which case there is only one speed at which the calender may be driven and the production is accordingly limited. The threading-in speed or slow speed at which the stock is started in the calender is obtained by allowing the friction clutch between the calender and the motor driving it to slip until the stock is started. The clutch is then gradually thrown in until the calender has obtained its full speed. The starting of the motor is accomplished by hand with the standard auto-starter or compensator, or by push button with a magnetic type starter. Overload and no-voltage protection are obtained by relays with either type of control, and push button stations, opening the no-voltage release circuit, furnish a convenient means for stopping. Four of these buttons, located one on each side of each leg of the calender, should be provided. A mechanical brake provides one of the most effective means of securing immediate stopping. Such a brake should be located on the end of the motor shaft opposite the driving gear.

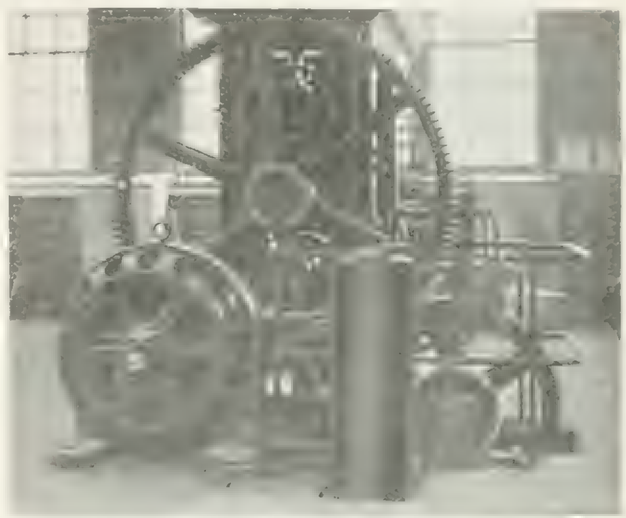

FIG. 3—[illegible]

WOUND SECONDARY MOTOR DRIVE

The second method of drive to be considered is by a wound secondary motor on an alternating-current circuit. This method is limited in production because of the fact that although wound secondary motors are stable in operation at fairly constant loads, down to 50 percent of full-load speed, their speed regulation is poor except for a small speed range and a reduction of more than 15 percent below full-load speed can hardly be considered for the work. The control for an installation of this kind will consist of a drum type controller with armature resistance sufficient to reduce the motor speed to about one-third of full-load speed for threading in (this portion of the resistance need be for intermittent service only) and resistance for continuous operation between 20 percent below full-load speed and full-load speed. Over-

load and no-voltage protection is obtained by a separate oil circuit breaker and stopping stations are provided as described in the first method. The mechanical brake is the only means of providing quick stopping of the calender with this method of drive.

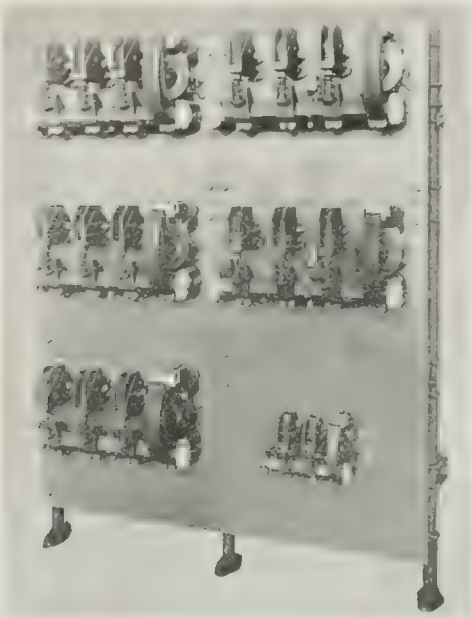

FIG. 4—MAGNETIC SWITCH CONTROL PANEL FOR AN ALTERNATING-CURRENT CALENDER MOTOR EMPLOYING THREE FREQUENCIES AND FIVE SPEEDS

TWO-SPEED SQUIRREL CAGE MOTOR DRIVE

A method of drive of slightly greater flexibility than either of the above is obtained by using, instead of the standard squirrel-cage motor as described in the first method, a two-speed squirrel-cage motor, the two speeds being obtained by changing the primary connections of the motor. The controlling apparatus is the same as described in the first method of drive with the addition of a knife switch for changing the motor connections. This method of drive gives two operating speeds of the calender, the threading-in for either speed being obtained by a friction clutch as described in the first method.

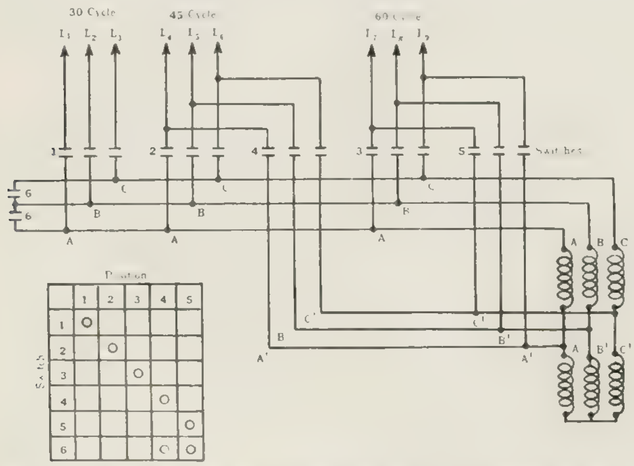

FIG. 5—SCHEMATIC DIAGRAM INDICATING THE OPERATION OF A THREE FREQUENCY, FIVE SPEED MAGNET SWITCH CONTROLLER

The above methods of drive are used only in rubber manufacturing plants having a limited variety of output and, therefore, mainly small plants. In the large plants, having a number of calenders and manufacturing a variety of product, it is economy to go to the expense of providing circuits of such character as to allow considerable variation in speed of the motors driving the calenders. In a rubber plant all apparatus, with the possible exception of the calender, is preferably driven by alternating-current motors and, since this is the larger portion of the power requirements, the power houses are naturally equipped with alternating-current apparatus.

THE MULTIPLE-FREQUENCY SYSTEM

To avoid the conversion losses incident to obtaining direct current for the calender motors, (which naturally suggests itself as a means for obtaining variable speed), some manufacturers have adopted a "multiple frequency" system of calender drive. This consists in providing generating equipment for two or more frequencies; for instance one company uses 45 and 60 cycles and another 30, 45 and 60 cycles. On these circuits, two speed squirrel-cage induction motors are operated, giving very close speed regulation on the various speed points. Using 10-20 pole motors on the 45 and 60 cycle circuits, operating speeds of 270, 345, 540 and 690 r.p.m. are obtained, and with the same motors on the 30, 45 and 60 cycle circuits, 175, 270, 345, 540 and 690 r.p.m. are obtained. Controllers for this type or drive may be of either the drum or magnetic switch type, the principle of the control being to get the motor on the various circuits in proper sequence and to have a sufficient interval of time between the various connections to allow the magnetization of the motor to decrease before making the next connection. This is particularly important with the drum type controllers since the small space available may mean that any considerable flashing will cause one circuit to flash over to another. Fig. 2 shows the scheme of connections of a drum controller for this service and Fig. 3 shows an installation of this kind. This controller has heavy renewable contacts mounted on flexible fingers making contact with segments on a movable drum. To secure the time interval between contacts an automotoneer is provided on the controller or an idle contact is introduced between the live ones. Overload and no-voltage protection and stopping stations are secured by an oil circuit breaker. Braking is secured by a

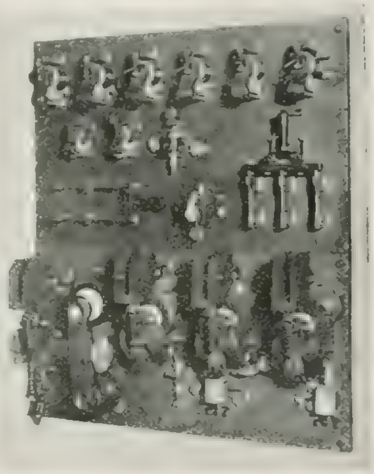

FIG. 6—PANEL CONTROLLING THE OPERATION OF TWO VOLTAGE DIRECT-CURRENT CALENDER MOTOR

mechanical brake as described under the first method of drive.

Instead of the drum controller, a magnetic controller may be used. This gives the advantages of controlling the calender from a distance without running heavy current carrying leads to the point of control, making all contacts visible and easy to repair and

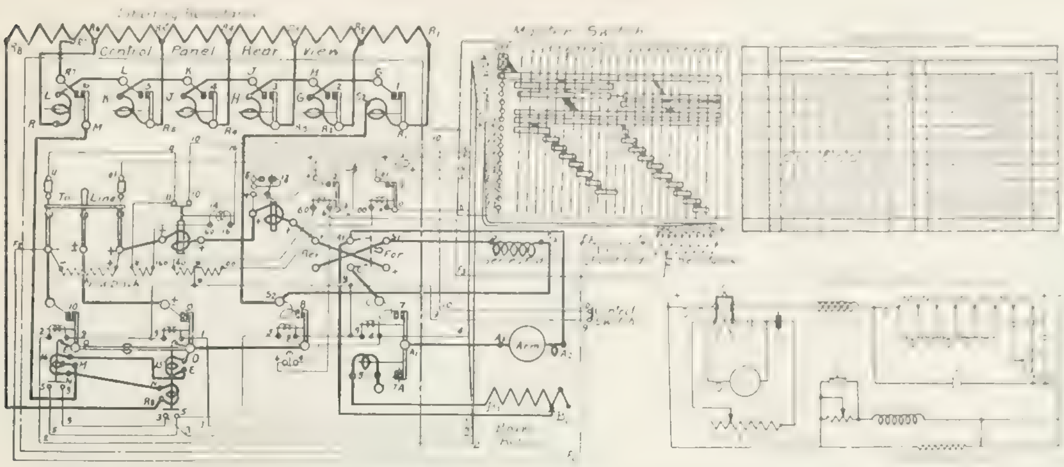

FIG. 7—DIAGRAM OF CONTROL FOR DOUBLE VOLTAGE DIRECT-CURRENT SERVICE FOR RUBBER CALENDERS

furnishing easy manual operation and self-contained protective devices. Fig. 4 shows a controller of this type, the three-pole magnetic switches being operated from a single magnetic switch and making connections to the various circuits as shown in Fig. 5.

DIRECT-CURRENT MOTOR DRIVE

The next method of calender drive to be considered is by direct-current motors. This method, as far as the calender drive is concerned, is without doubt the one that combines the greatest number of advantages because of the facility and convenience of control. A wide range of speed, a large number of operating points and all practical protective features are obtained with this method. A speed range of four to one is ample for all conditions of work and, because of the difficulties of design and cost of motors of the size required for this work (50 to 150), having this range of speed by field control, it is usual to employ motors having a speed range of one to two by field control and obtain the total speed variation of four to one by operating the armatures on two voltages. Some manufacturers consider a speed range of three to one sufficient and secure the lower part of the speed range by varying resistance in the armature circuit; also in one prominent plant, three voltages are used but by far the most common employment of direct current for this work is the two voltage circuit. The two voltages may be obtained from three-wire generators or by bringing out the neutral point of transformers connected to rotary converters, to form the middle point of a 125-250 volt circuit. This latter method is in use in small plants desiring the maximum variety of production and convenience of operation and purchasing power from central stations. It is economical of operation and simple to install.

The control for the calender motor operating on such a system consists of a master switch operating a magnetic control panel containing provision for accelerating the motor by cutting out resistance in the armature circuit until the full speed on the 125 volt circuit is reached; ten speed points by variation of field resistance on this circuit; transfer switches, changing the motor armature to the 250 volt circuit and at the same time cutting out the field resistance; and ten speed points by variation of field resistance on the 250 volt circuit. A three-pole knife switch is provided for connecting the motor and control circuits to the line and a two-pole knife switch for reversing the direction of rotation of the calender, if this should be required. Overload and no-voltage protection is obtained by series and shunt relays actuating the magnetic switches in the line circuits. Dynamic braking when the calender is shut down is obtained by a back contact on one of the line switches. Such an outfit may be started and stopped by means of push buttons and it is usual to provide each calender with four "start" and "stop" stations. On pushing the start but-

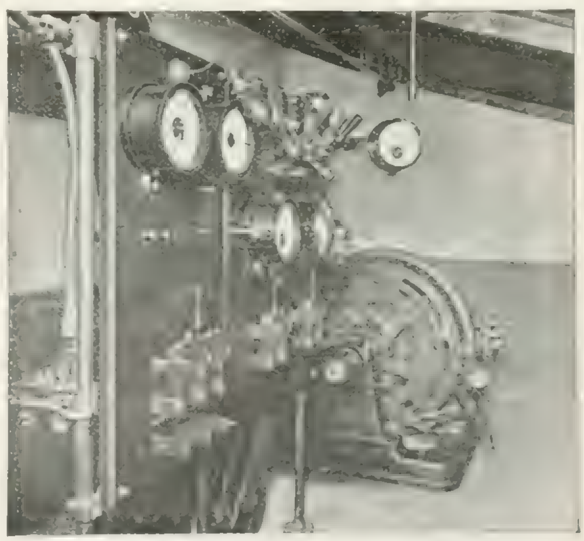

FIG. 8—ROTARY CONVERTER AND SWITCHBOARD FOR DIRECT-CURRENT RUBBER CALENDER UNIT

ton the motor accelerates by lockout switches on the armature circuit and fluttering relays in the field circuit, to a speed corresponding to the setting of the master switch. Pushing the stop button or bringing the master controller handle to the off position, disconnects the motor and control from the line and causes the motor to be braked dynamically, bringing it to rest immediately.

Automatic Control for Laundry Machines

DRIVEN BY ALTERNATING-CURRENT REVERSING MOTORS

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THE successful application of alternating-current reversing motors to washing machines depends largely upon the type and reliability of the control used. It is essential that each washer reverse its direction of rotation seven to nine times per minute, so that the clothes in the washer cylinder will not become entangled. Each motor is connected directly to the line and is reversed from practically full speed in one direction to full speed at full load in the other, by simply opening the magnetic circuit of one two-pole contactor and closing the magnetic circuit of another, the contactors being mechanically and electrically interlocked to prevent any possibility of short-circuit. The time between the opening of one contactor and the closing of the other is approximately one second. A typical installation of this type of control together with the wiring layout is shown in Figs. 2 and 4. This controller is arranged to take care of five reversing motors, driving washers; one reversing motor, driving a dry room tumbler, and three non-reversing extractor motors.

H. F. BOE

There are four essential features embodied in this type of control:—

1—A reliable timing device and magnetic circuit reversing switch.
2—Contactors, mechanically and electrically interlocked, equipped with blow-out coils and of sufficient size and strength to stand the severe service to which they are subjected.
3—A dependable series relay to prevent disturbances to the line.
4—Push button stations for starting and stopping.

The first of these features, viz. the timing device used in connection with this installation, consists of a single-pole, double-throw, right angle switch operated from the washer shaft through a silent chain and time gears, each washer being equipped with its own individual timer. The switch opens and closes the coil circuit of the contactor. The time of each cycle depends upon the speed of the motor; hence, if the load is light, the motor will reverse more times per minute than if the load is heavy, although the washer cylinder makes the same number of revolutions before reversing under any load condition.

FIG. 1—A 30 INCH SOLID CURB EXTRACTOR

Driven by a three horse-power, 1 200 r.p.m. vertical induction motor controlled by a push-button station, which opens and closes the magnetic circuit operating the individual contactors shown on the panel of Fig. 4.

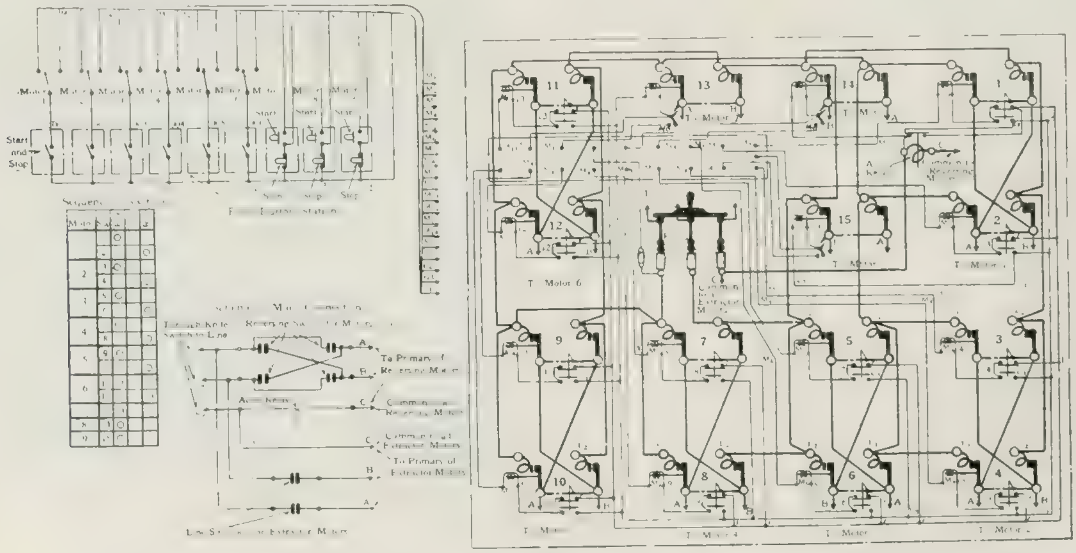

FIG. 2—WIRING DIAGRAM OF CONTROL PANEL SHOWN IN FIG. 4

The contactors, as shown in Fig. 1, are mechanically and electrically interlocked, are equipped with magnetic blow-out coils and are large and rugged in construction. Each of these two-pole contactors opens and closes about four times per minute during the entire run.

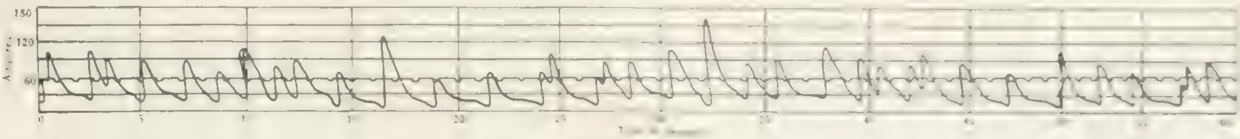

FIG. 3—LOAD [illegible]

Covering five three-phase, 60 cycle, 220 volt 1 140 r.p.m. reversing induction motors. The curve is taken from one phase of the line and the extreme peaks are due to over-travel of the pen. Each motor reverses above once every eight seconds.

The relay is in series with one phase of the power circuit and opens or closes the magnetic circuits of the various switches depending upon the current in the line, interlocking contacts being provided which prevent any of the reversing motors from starting when the relay is open, but make any switch which is closed independent of the relay. This relay can be adjusted so that no two motors can start or reverse at the same time. However, where more than three motors are controlled by one relay, two motors are usually permitted to reverse at the same time, since if only one motor be reversed, each machine will come to rest before reversing and thus cause a loss of time which is objected to by the laundrymen. Fig. 3 demonstrates that the proper adjustment of the relay reduces the disturbance in the line to a minimum. The push button stations are located on each washer as indicated in Fig. 5, and are used for starting and stopping only, the control being entirely automatic when the push button is in the "on" position.

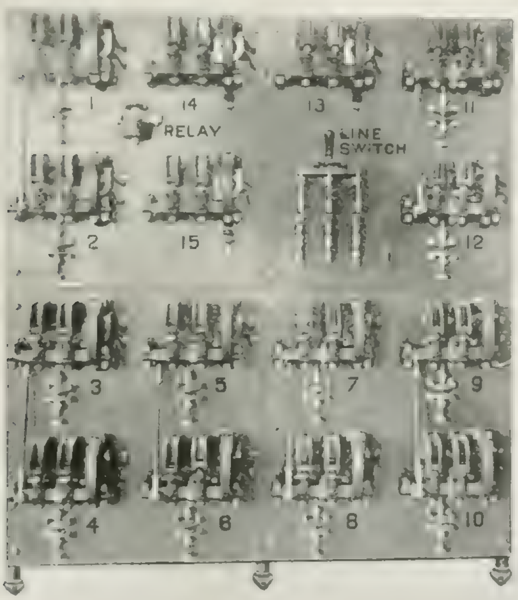

FIG. 4—LAUNDRY CONTROL PANEL

Covering five reversing washing machines, one reversing dry-room tumbler and three extractors. The relay governs the operation of the reversing washing machines, preventing the reversal of more than two at one time. The switches are numbered to correspond to the wiring diagram shown in Fig. 2.

The dryroom tumbler motor shown in Fig. 6 has a control identical with that of the washing machines

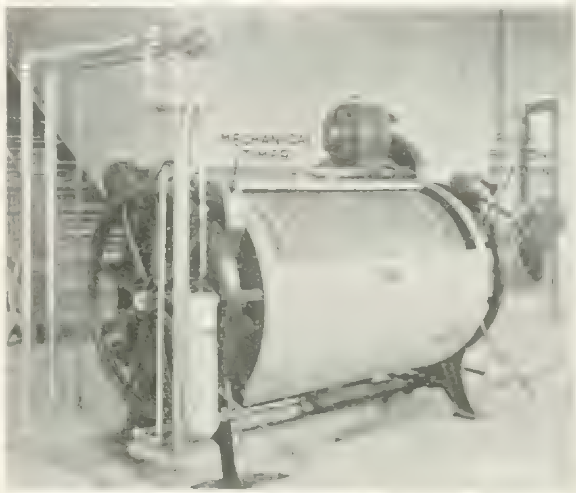

FIG. 5—[illegible]

and is interlocked through the relay with them. The extractors, however, as shown in Fig. 1, are controlled separately and driven by three 3 horsepower, three-phase, 60-cycle, 220 volt, 1 140 r.p.m. vertical motors. These motors are connected directly to the line by closing the individual contactors on the control panel by means of push button stations located on the extractor frame as shown in Fig. 1.

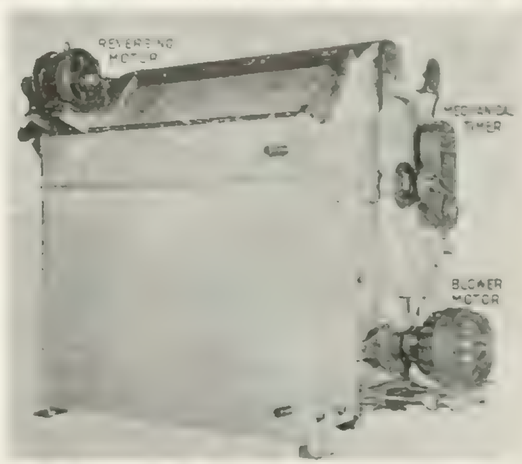

FIG. 6—A 42 BY 60-INCH DRY-ROOM TUMBLER
Driven by a reversing induction motor.

This control panel is also provided with one main line three-pole switch and cartridge fuses, the control circuit being protected by a small cartridge type fuse.

The Manufacture of Electric Controllers

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Controller Manufacturing Dept.,
Westinghouse Electric & Mfg. Company

PROBABLY in no branch of the manufacture of electrical apparatus is there so wide a variety of parts and combinations of parts as in the electric controller for industrial motors. A large variety of types of motors has been developed to meet the rapidly increasing applications of electric drive to industrial fields, such as mill motors, elevators, machine tools, etc. Whereas formerly the controller or starting rheostat was considered as a minor auxiliary in an electrical installation, the electric controller of today has become an important piece of apparatus which has gradually developed, due to the more exacting demands for the operation of motors with greater safety, with predetermined acceleration and deceleration, and with different speeds.

J. A. BLICKMAN

From a brief review of the many types of present-day motors, both alternating and direct-current, with either constant or variable speed in their many branches of application, it can readily be appreciated that, in addition to the standard lines of electric controllers, the manufacturer is compelled to design and construct an extensive line of special controllers for individual cases. Under such circumstances, instead of attempting to standardize the complete control, the logical procedure was to devote attention to the development of the details; that is, to standardize individual parts and dimensions to the greatest possible extent, the special features of manufacture thus being narrowed down practically to the manufacture of magnet switches, relays and auxiliaries and their grouping into control panels. This is exactly what has been done in the evolution of the magnet switch, the production of which in quantity has presented a very interesting manufacturing problem.

THE MAGNET SWITCH

In the development of this switch the underlying principle has been to meet the greatest possible number of requirements with the least possible variety of parts. To this end a thorough analysis of the requirements of the varied applications was necessarily the initial step, resulting in the decision that the following essential features must be incorporated in such a switch for general application:—

1—Substantial construction.
2—Durability.
3—Thorough insulation.
4—Uniformity of design and construction.

These requirements in a switch for universal use are, of course, in addition to the general characteristics of any successful switch, such as reliability, accessibility, liberal contact design and simplicity.

The first of the above general requirements is answered in the design, by specifying a sufficient amount and proper arrangement of material, and in the assembly by careful workmanship and provision for ample pressure for all riveting and bolting.

The second requirement is answered in part by the first, in securing mechanical ruggedness, and in part by the use of protective finishes. As a general rule the installation of an electric controller in damp and exposed places does not call for elaborate finish, but rather more attention has to be given to rust resisting coatings on all working parts. Where lubricating is entirely eliminated, such processes as sherardizing and coslettizing have been applied to the working parts of the switches and relays. Sherardizing means exposing the iron or steel parts under a high temperature to zinc fumes. This causes an alloy of zinc and iron to be formed and finally a thin coating of zinc is deposited on the surfaces thus exposed. This process successfully replaces the older method of electro-plating which sometimes will rust under the coating and scale off. The process known as coslettizing is a more recent development and consists merely in boiling the parts in a chemical solution. It replaces the old method of blueing the parts in oil and gives an equally pleasing appearance, besides being a better rust preventive.

The extra insulation is provided by a thorough impregnating and baking of the coils, substantial spool construction, arc shields on contacts, and ample spacing between parts of different potential.

The above three features provide protection against the mechanical impact and vibration due to the operation of the switch itself; against the destructive or corrosive action of damp or otherwise harmful locations, and against abnormal voltage conditions. The fourth essential is that which makes possible economy in the cost and time of manufacture, and will be considered in its details.

MANUFACTURE

From a manufacturing standpoint the design of the magnet switch in its principal details has been kept very uniform. This has allowed the introduction of combinaton tools and fixtures, as only the principal dimensions are changed to accord with the capacity of the switch unit. Where the design demands the use of castings it is found that the shape of the casting may be made strictly uniform. When punched parts are permissible, as indicated in Fig. 1, there is an extensive use for each part so made, thus not only saving in the weight of material, which is

considerable on account of the quantity of parts made, but also resulting in a minimum of labor cost, (the initial investment in tools being small in comparison with the saving in labor) and finally insuring accuracy in dimensions. Parts requiring extensive machining are designed so as to make possible their manufacture on automatic machine tools and these

FIG. 1—COMPARISON OF CAST AND PUNCHED PARTS

Indicating the difference in the cost of labor involved in the manufacture.

parts will be found common through the complete line of switches, thus guaranteeing quantity manufacture. Other parts again, such as arcing tips, are manufactured from drawn stock material, the only variation in dimensions for different capacities being in length, which is obtained by a single cut off on the saw. For the assembling of details, standard hardware, such as bolts, washers, taper pins and spring cotters are used; and such details as shafts for contact arms, etc., which require quick removal are secured by means of receding pins under spring locks and spring cotters. The same uniformity is found in the design of the frames, which are built up from standard pipe clamped together with standard clamps and "U" bolts and carrying uniform braces to which the switch bases are bolted.

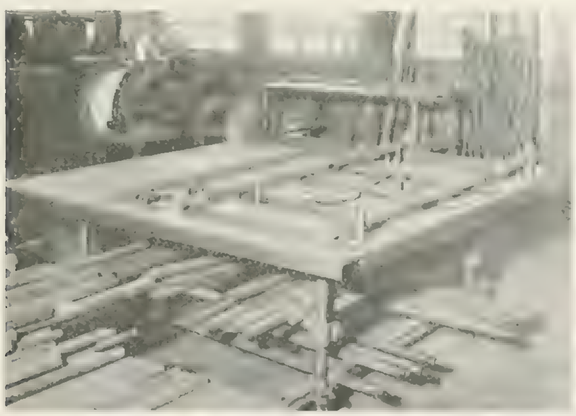

FIG. 2—ASSEMBLY TABLE FOR THE PIPE FRAME MOUNTINGS OF CONTROL PANELS

By means of this table quantity lots of a given size can be assembled in very rapid order.

As soon as a standard design was established, the manufacture was started with a considerable expenditure for the necessary tools and permanent metal patterns, as production in quantity was anticipated. Each tool, as shown in Fig. 3, is provided with hardened gage blocks, stops and other means of checking dimensions, to which the operator sets his cutting tool. The detail parts, having received their prime coating of paint in the dipping tank, are brought to the tool and one piece is machined. This is then removed and examined with working gauges for accuracy of dimensions and allowances. If these check, the ma-

FIG. 3—MACHINE [illegible] MAGNET SWITCHES

The operator is shown setting his tool in accordance with the stops and gage blocks.

chine is again put in operation and the workman completes the lot. In this way the details run through a series of operations from milling fixture to drill jig, to tapping fixture and so on, on machine tools conveniently located in the proper sequence; thus insuring a minimum of transportation, as they travel almost in straight lines from machine to machine into the assembling department or the storeroom.

The same system is carried through in the assembling departments, where groups of workmen assemble complete style parts for stock and others assemble these style parts into complete switches by

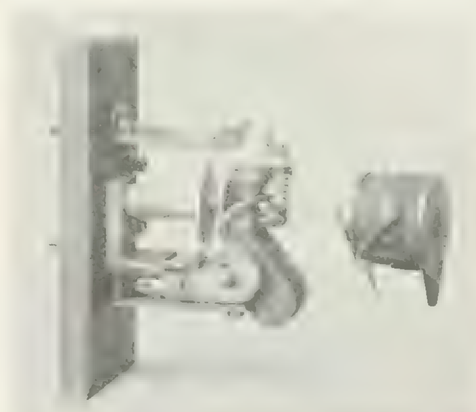

FIG. 4—[illegible]

The coil is not assembled with the rest of the switch as it is only applied when the requirements of the service are specified.

withdrawal of parts and hardware from the storeroom. The production of individual switches is thus automatically regulated by withdrawal from the storeroom and consists merely of replenishing the stock of parts and of complete switches. An important feature of stock production with standard tools under severe

inspection, is the possibility of interchanging parts in cases of inevitable breakdowns or wear outs, without any extra fitting or loss of time in delivery.

ASSEMBLY

The workman assembles to predetermined allowances for distance between contacts, distances between magnetic surfaces; and contact spring compression, as each carries a distinct relation to the others. As variations of one-thirty-second of an inch are considered as maximum allowance, working gages are constantly used. The contact surfaces in the closed position are the copper tips alone, the carbon being entirely free. The heels of these copper tips must form a straight line without overlapping. When the switch opens the moving element transfers the contact to the upper part of the tip, finally breaking the circuit on the carbon. It is also necessary to provide a uniform compression in the spring opposing the pull of the magnet. Considerable attention is given to the assembling of the laminated armature and poles, as to the steel used, the uniformity of the lamination insulation and the riveting and bolting pressures, so as to insure quiet operation on alternating-current circuits.

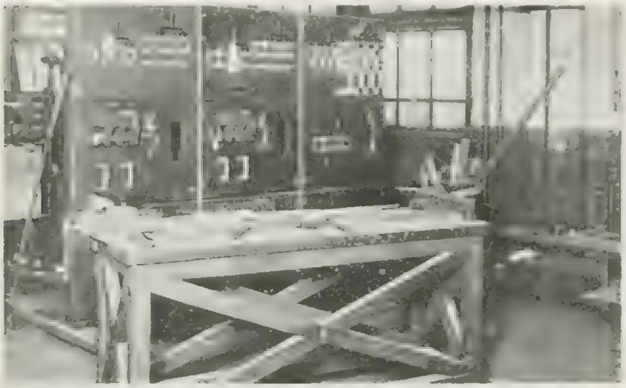

FIG. 5—EQUIPMENT USED IN THE ASSEMBLY OF COMPLETE CONTROL PANELS

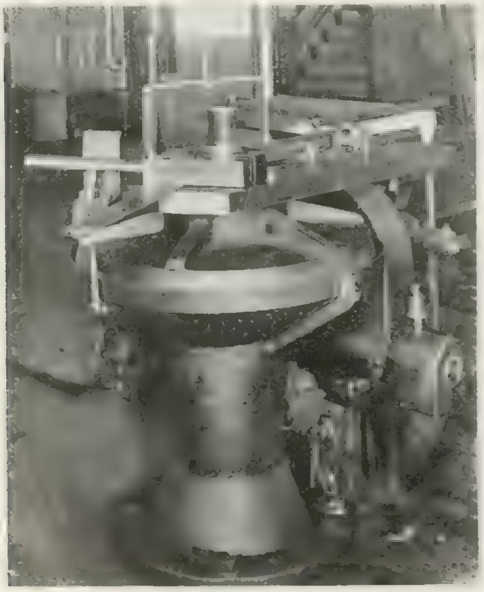

FIG. 6—BENDING MACHINE ON WHICH THE HEAVIEST STRAP WIRE IS BENT TO ANY FORM DESIRED

An example of a magnet switch as it would be sent to the storeroom is shown in Fig. 4. With the exception of the coil, the parts are all standard and are accordingly assembled before assignment to stock. The coil, however, incorporates the variable features such as voltage, and therefore is only applied on the withdrawal of the switch from stock to fill an order of definite characteristics.

The assembly is started by withdrawing the necessary parts from stock. Then the slate bases for the switches, relays, interlocks, etc., being of standard dimensions, are assembled on standard pipe frame mountings. The workman is equipped with convenient assembly tables, tools and wheel truck, as indicated in Fig. 5. In wiring up the back of a control panel the workman is very much assisted by the strap-bending machine shown in Fig. 6. The different sizes of copper strap can be bent by this means to any desired angle, as indicated in Fig. 7.

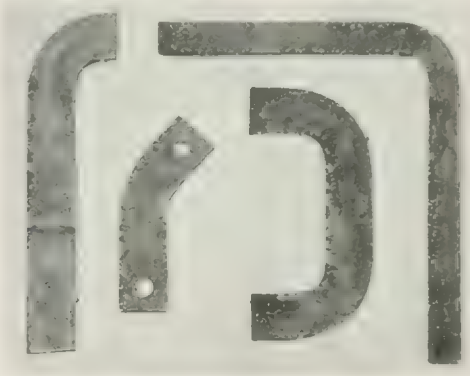

FIG. 7—COPPER STRAP BENT ON THE BENDING MACHINE SHOWN IN FIG. 6

INSPECTION AND TEST

A thorough system of inspection follows the apparatus through the shop. As already stated, the dimensions to which the pieces are machined are carefully inspected on completion of the first piece; then on completion each individual switch, relay, interlock, etc., is checked for mechanical correctness of dimension and operation; and, finally, when assembled on a complete control panel, the whole apparatus is given a last mechanical check and wherever possible is wired complete with resistance and master controller to a motor-generator set and run under actual working conditions. Also each switch on the panel is tested separately as to its proper insulation, magnetic condition and energy consumption, the requirements being especially exacting on alternating-current circuits.

As the control panels are wired complete in the manufacturing department and transported to the testing and shipping departments without dismantling, they are mounted on vans provided with casters, thus facilitating the handling.

The methods described above reduce the manufacture of the magnet switch and the complete control panel to a perfect manufacturing procedure, which not only facilitates its passage through the shop on its way to completion, but also simplifies the system and minimizes the time before delivery or shipment.

The Engineering Evolution of Electrical Apparatus—VI

THE EVOLUTION OF INDUSTRIAL CONTROLLERS

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Engineer in Charge
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IN THIS article controllers are considered to be those devices which are used for starting, stopping, reversing and controlling the speed of motors. Starting rheostats, hand operated, used for infrequent starting of motors are not included. As the article is of an historical nature, the aim has been to describe and illustrate devices and their principal parts in such a way as to show their evolution and to point out some of the features which have been prominent in this development. It is an interesting fact that in many cases the evolution is through the complex to the simple.

IT SEEMS almost inevitable that the designer must follow a circuitous path which takes many different directions instead of finding the straight and short path which leads to the perfected simple device. This is shown by the evolution of controllers which, beginning with a few simple switches, has developed through many different forms of complex mechanism to the highly developed unit switch of today, which in various combinations is used to a large extent in the solution of control problems. A study of the development of resistors shows the same thing. They were first made by winding resistance wire on an insulated supporting member. Later, various forms were used, such as the cell type and the imbedded type,

T. S. PERKINS

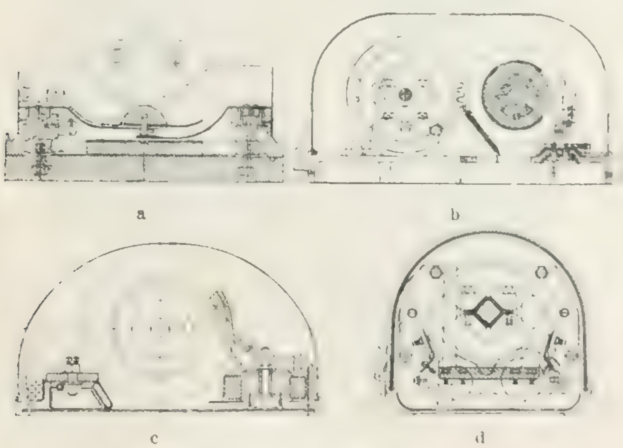

FIG. 1—SECTIONS SHOWING DEVELOPMENT OF DRUM CONTROLLER CONSTRUCTION

but at the present time very simple forms are used, such as the grid, bar, bobbin and tube types.

EARLY CONTROLLERS

In its simplest form, a controller consists of two single-pole, single-throw switches and a suitable resistance. Closing the first switch connects the motor to the circuit with the resistance in series, and closing the second switch short-circuits the resistance. If reversing is necessary, a double-pole, double-throw switch is used. While the control problem was one of a comparatively simple nature in the early days, at present the application of motors in industrial work has become so diversified that there are now many forms of controlling devices with a large variety of functions to perform.

One of the very first applications of electric motors requiring controllers to industrial work was the case of electrically-operated cranes. In this application there was one motor for moving the bridge, one for the carriage and one for the hoist. These controllers were used for starting and controlling the speed of the motors by introducing more or less resistance into the circuit, and for reversing the motor. The earliest form of controller used for this purpose was the so called drum type and was made by modifying the street car controller. A sectional view of one of the very early forms of drum controller is shown in Fig. 1-*a*. It will be noted that this controller consists essentially of a drum with bearings at each end and copper segments with insulated discs between the segments. Contact fingers were arranged in such a way that the desired circuit and motor connections could be made. One of the difficult problems in early controller work, or as a matter of fact in all controller work, was to reduce the amount of destruction caused by the arc which is formed in opening the circuit. It is also necessary to isolate the arc so as to prevent it from

FIG. 2—THE MAGNET SWITCH IN AN EARLY FORM

taking a path to adjacent contacts which would form a partial or complete short-circuit, as well as to reduce the damage due to arcing when the circuit is opened. It will be noted in Fig. 1-*b* that the drum on which the contact segments are mounted is made of fire-proof material or is covered with such a material. In the early days there were not so many nor so suitable materials as now exist for this purpose. At first wooden drums were used. It was found that the arc due to the opening of the circuit or to cutting in resistance

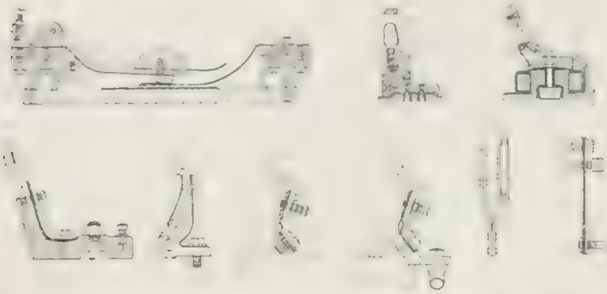

FIG. 3—SKETCHES SHOWING THE EVOLUTION OF THE CONTACT FINGER

soon charred the wood, not only destroying it, but quickly making the surface conducting, due to carbonization. The drum was covered with sheet asbestos, which was an improvement. This, however, was not durable and the construction consisting of porcelain discs with insulating shields between the discs was used. A considerable amount of development work was done in order to get a porcelain which would not chip and crack under the heat of the arc. Considerable attention was also given to getting a material for the insulating shields used between the porcelain discs that would not become conducting when exposed to the arc. As the work became more severe and the motors larger, the use of metal drums was resorted to. The general features of this construction are shown in Fig. 1-*d*. This construction consisted of an insulated shaft with cast metal segments clamped to it.

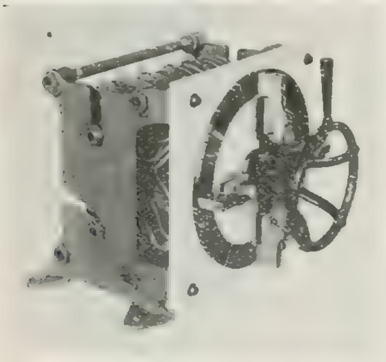

FIG. 4—EARLY FACE-PLATE CONTROLLER

INTRODUCTION OF MAGNETIC BLOWOUT

The destruction of the contacts as well as the difficulty of opening heavy currents with any considerable voltage was still a most troublesome matter and the magnetic blow-out was resorted to. The use of the magnetic blow-out for suppressing arcs stands out as one of the very prominent and important steps in the development of devices which have to perform this function. As a matter of fact it has probably contributed more to the development and advance in arc rupturing devices for direct-current circuits as well as to a considerable extent in alternating-current circuits than any other one thing. The earliest form of the application of the magnetic blow-out was the use of one coil to produce a magnetic field by means of iron arms extending over the controller fingers which acted to blow out the arc quickly. The magnetic blow-out scheme has been applied in various other ways, one being to place a coil at each side of the point of engagement of the contact fingers and contact segments so as to produce a magnetic field at the point where the arc is formed and to blow it in a plane parallel to the finger. One of the particular advantages of this arrangement is that the arc is carried away from the fingers and contacts and does not strike the insulating arc shields between contact fingers and thus the life of the shields is lengthened and possible short-circuits between fingers avoided. Fig. 2 shows its application to a modern magnetic unit switch.

FIG. 5—LATER FORM OF FACE-PLATE CONTROLLER

Before the use of the magnetic blow-out was resorted to, one of the schemes was to arrange the controller so that the arc was formed with a large number of breaks in series, thus distributing the burning over many contacts and making it easier to confine the arc at any one of the points where it occurred. Immersing the contacts in oil was tried in early direct-current controllers but this proved of doubtful utility.

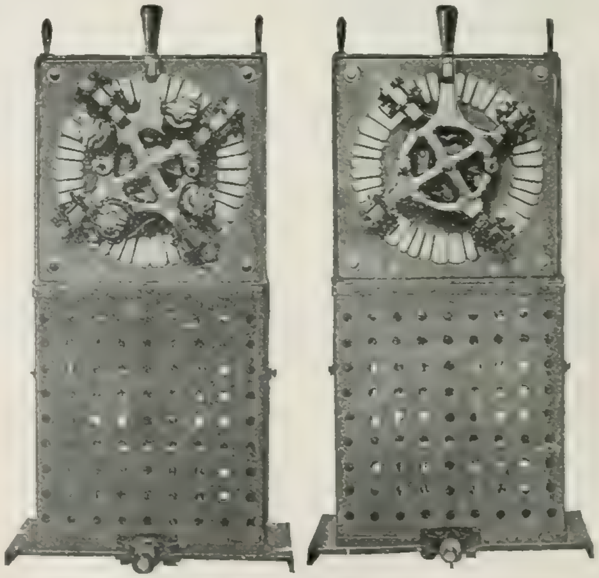

FIG. 6—FACE-PLATE CONTROLLERS WITH RESISTANCE MOUNTED BELOW

With and without blowout coils

CONTACT FINGERS

A very important element in controllers, especially of the drum type, is the contact finger. It has received a great deal of study and has passed through many stages of development. Fig. 3 shows a number of different contact fingers in the order of their development. In the first one it will be noted that the contact finger is a large and a more or less complicated mechanism as compared with the more modern construction. It is a difficult matter to get a finger which is reasonably cheap to manufacture, which is easily renewable, which will carry the current without overheating, which is easily kept in operating condition and which is readily adjustable. The accompanying illustrations show only a few of the types of fingers which were used and is confined to those which have had application for a considerable time. However, there were many other forms introduced and tried out, a good many of them having no other excuse for their existence than the confidence or perhaps pride of the designer. For many years it was a regular thing for an engineer, soon after he had taken up the work of designing controllers, to get up a new type of contact finger. A study of these designs in many cases made it evident at once that he had just taken up the work.

FIG. 7—FACE-PLATE CONTROLLER FOR SMALL MOTORS

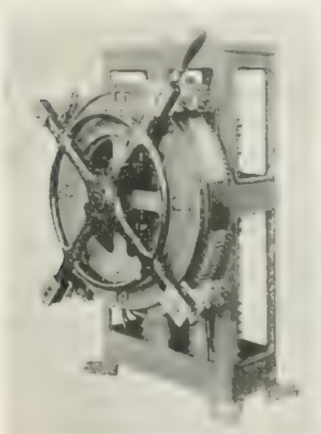

FIG. 8—THE FIRST COMMUTATOR-TYPE CONTROLLER

FACE PLATE AND DISC CONTROLLERS

The next type of controller developed was made in two forms, the face plate and the disc form. The former had the contacts mounted on the surface of marble, slate or other insulating material, and the latter had the contacts mounted on the periphery of a circular supporting member. The former was commonly called the face plate controller, and the latter the commutator type, disc type and grindstone type, according to the form of construction used. The face plate type was first made as shown in Fig. 4. A later form is shown in Fig. 5. In order to economize in floor space, especially when used in crane cages, the resistance was later mounted below the face plate. Fig. 6 shows two forms, one with magnetic blow-out and the other without magnetic blow-out. This controller is, in many of its essential features, the same today as when it was first brought out about 1892. The op-

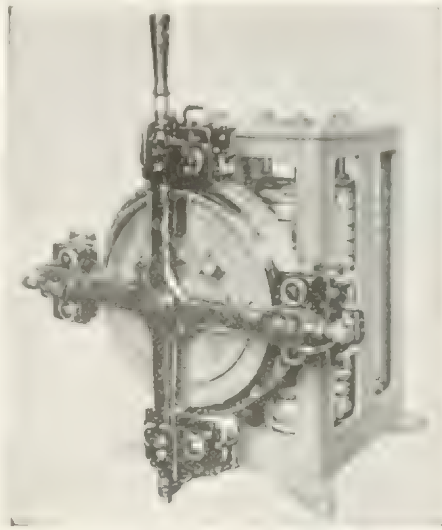

FIG. 9—COMMUTATOR TYPE CONTROLLER WITH MAGNETIC BLOW-OUT AND RENEWABLE CONTACTS

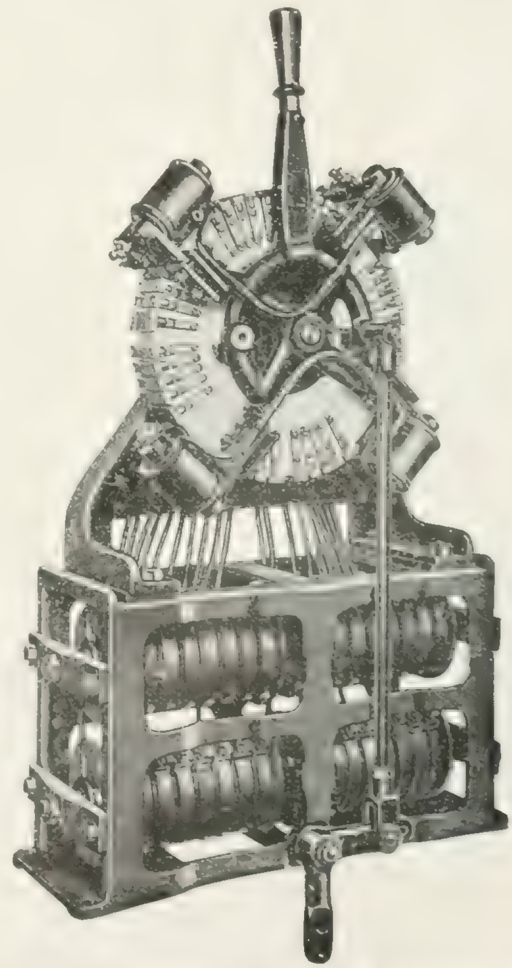

FIG. 10—GRINDSTONE TYPE CONTROLLER WITH RESISTANCE MOUNTED BELOW

erating handle moves in each direction from the off position to get forward or reverse operation of the motor. Reversing was obtained without the use of a separate reverse switch. This feature is described in more detail later. Another form of controller for small motors is shown in Fig. 7. The other form of this type of controller was first made up in the so

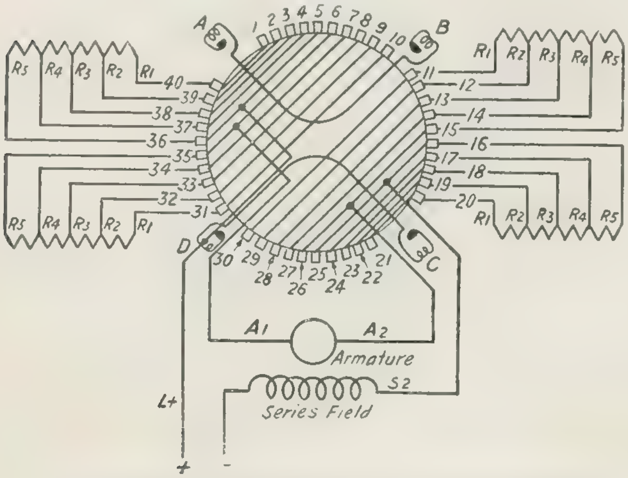

FIG. 11—DIAGRAM OF CONNECTIONS OF A FACE-PLATE AND COMMUTATOR-TYPE CONTROLLER

called commutator type. As the name implies the contacts were built up like the commutator of a direct-current motor using V-ring construction. This fulfilled the requirements of ruggedness and durability, and endured for many years. Fig. 8 shows an early form of this controller. In Fig. 9 a later form with magnetic blow-out and renewable contact segments is shown. One of the early applications of this controller in particularly severe service was on cranes for charging soaking pits in steel mills. In this work sensitive control of speed was not desired, but quick starting, stopping and reversing of the motor was necessary. The controller was made with comparatively few well-separated contacts, and strong magnetic blow-out and low ohmic resistance. In order to save floor space this form of controller was later made up with the re-

FIG. 12—FACE PLATE CONTROLLER FOR SQUIRREL-CAGE MOTORS

FIG. 13—SEGMENT TYPE OF CONTROLLER FOR SQUIRREL-CAGE MOTORS

sistance mounted under the contacts, as shown by Fig. 10. In order to get a less expensive form of construction than the commutator type, the grindstone type was developed. In this a disc of soapstone or other suitable material is used and the contacts secured to the periphery. This construction is shown by Fig. 10. The magnetic blow-out was applied in such a way as to blow the arc parallel to the contacts. This proved effective and made the contacts very durable under the most severe conditions of service. In the face plate and commutator type controllers just described a very ingenious scheme of connections was used so as to provide for many steps of re-

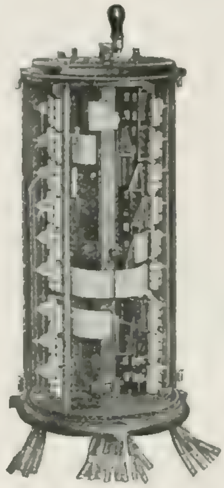

FIG. 14—DRUM-TYPE CONTROLLER FOR WOUND-SECONDARY MOTORS

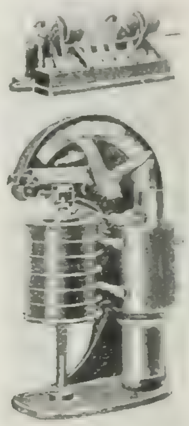

FIG. 15—EARLY TYPE OF AUTOMATIC ELEVATOR CONTROLLER

sistance with a direct-connected handle operating through a small arc of travel and to obtain reversing of the motor without a separate reverse switch. Fig. 11 shows a diagram of connections of this form of controller. It will be noted that the resistance is divided into four sections, and the contacts are staggered in such a way that a portion of the resistance is cut out of each section progressively. It will be further noted that when the contact fingers, of which there are four sets, are moved in one direction the current goes through the armature in a given direction, and when the fingers are moved in the reverse direction from the neutral or off position, the current in the armature is reversed. The whole scheme of this type

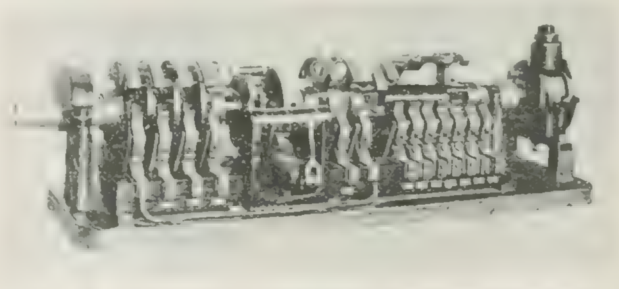

FIG. 16—MECHANICALLY-OPERATED AUTOMATIC ELEVATOR CONTROLLER

of controller, with its ingenious coördination of parts to perform its functions effectively, its campact and convenient form, make it deserving of a very prominent place in the history of all industrial control devices.

Alternating-current motors of the squirrel-cage type were first used in industrial work. One of the first controllers used in this connection is shown in

Fig. 13. Change in speed was obtained by applying different voltages to the motor. The voltage steps were obtained by bringing out leads from the windings of a transformer. In order to prevent short-circuiting a loop of the transformer in changing from one lead

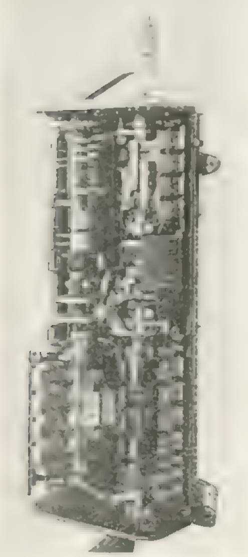

FIG. 17 — PRINTING PRESS CONTROLLER

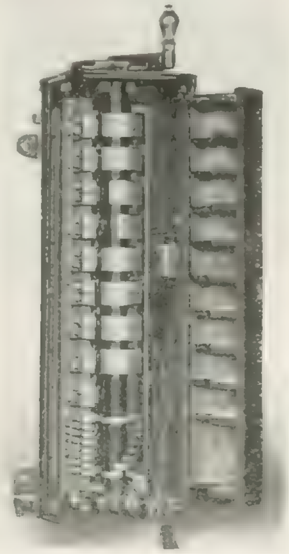

FIG. 18 — MACHINE TOOL CONTROLLER — DRUM TYPE

to another, a resistance was introduced between two sets of fingers of the controller. This form of controller was later made in the face-plate type, as shown by Fig. 12. To obtain better speed control, alternating-current motors were later designed with wound rotors and resistance was introduced into the rotor circuit. Fig. 14 shows the type of controller which was used for this service.

APPLICATIONS IN DIFFERENT INDUSTRIES

As the application of motors to industrial work became more general, the functions of the controller became more varied and it was necessary to develop types to meet the specific requirements. This was particularly true with regard to elevators, printing presses and machine tools.

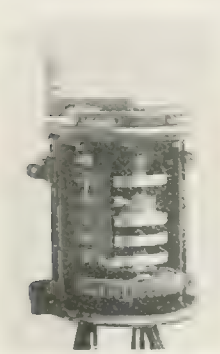

FIG. 19 — MACHINE TOOL CONTROLLER — COMBINATION DRUM AND FACE-PLATE TYPE

FIG. 20 — MACHINE TOOL CONTROLLER — FACE-PLATE TYPE

For elevator service, direct-current motors only were used at first, and the first step in automatic operation was the development of a controller having a solenoid to move the contact arm and a dashpot to produce a slow motion so that the time consumed in starting the motor was independent of the operator. Fig. 15 shows the earliest form of this controller. The starting and reversing switch was connected to the rope which passed through the elevator car. This was followed by an automatic elevator control which was entirely mechanically manipulated. Fig. 16 shows one of these controllers. The handle or operating wheel of the controller winds up a spring, the drum being held stationary by a pawl. At the end of the movement of the wheel the pawl is released, allowing the drum to revolve, due to the tension of the spring. A retarding dashpot was used to limit the movement of the drum and thus to make the time of starting independent of the setting of the dashpot and independent of the operator. A considerable amount of ingenuity found expression in the various forms in which these earlier automatic controllers were made up. This latter form of controller was also used in connection with the first application of alternating-current motors to elevator work. These motors were started by applying several steps of voltage. It was not desirable to open the circuit in passing from step to step, nor would it do to have two fingers on a common contact at the same time, as this would short-circuit the loops of the transformer; so in connecting to the next higher voltage a resistance was first introduced, and after the lower voltage was disconnected the resistance was short-circuited.

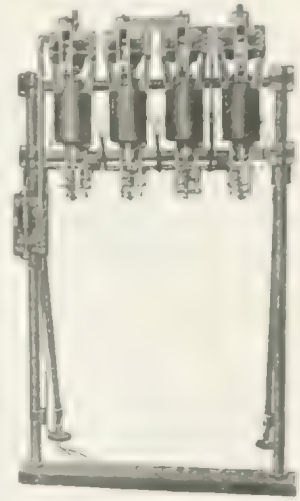

FIG. 21 [illegible] TROLLER — MAGNET-SWITCH TYPE

[illegible] NET SWITCH TYPE

The control requirements for electrically-driven printing presses, especially such presses as are used for printing newspapers, are most exacting. No at-

tempt will be made here to discuss the schemes of control now in use in modern newspaper offices. As a matter of interest, however, one type of printing press controller is illustrated and briefly described. This is shown in Fig. 17. The controller is of the drum type with magnetic blow-out as shown. Automatic devices are provided for opening the circuit in case of no volt-

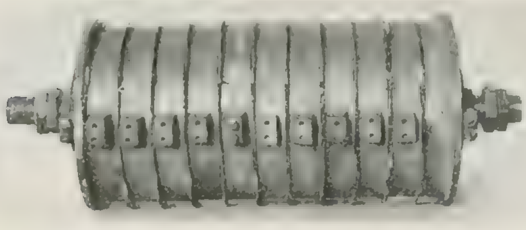

FIG. 23—COLUMN OF CELL-TYPE RESISTORS

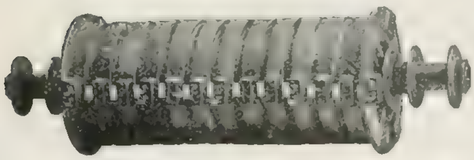

FIG. 24—COLUMN OF VENTILATED CELL-TYPE RESISTORS

age or overload, or if the operator removes his hand from the handle in any of the starting positions. Speed variation is obtained by varying the resistance in the shunt field of the motor and further by the use of resistance in the armature if necessary. Provision is made for connecting the armature to a resistance for electric braking. There are two positions, one for easy braking and one for emergency braking. A reverse

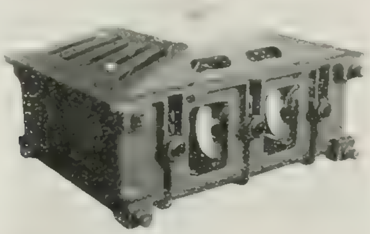

FIG. 25—CELL-TYPE RESISTORS IN CAST-IRON HOUSING

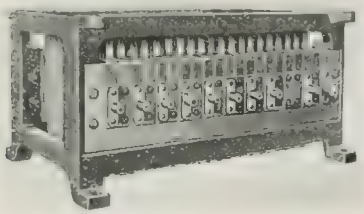

FIG. 26—EARLY FORM OF GRID RESISTOR

switch is provided. The motor may be stopped by means of push buttons located in any number of places. This controller was brought out about 1902.

In the application of motor drive to machine tools, speed control was obtained by the application of two voltages to the motor and by shunt field control. Later practice is to use a single voltage and obtain a complete speed control by varying the field current. The drum type of controller was applied to this work. Fig. 18 shows one of these controllers. A modification of this type is shown by Fig. 19. In this form the armature current is handled by the usual drum and fingers, whereas the shunt field current is taken care of by a

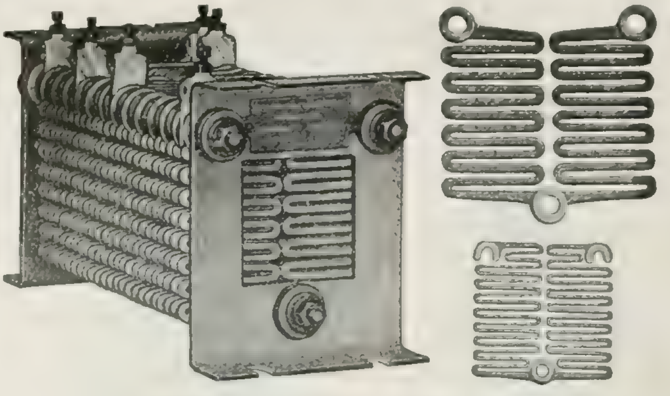

FIG. 27—MODERN GRID RESISTOR SHOWING MOUNTING AND THREE-POINT SUSPENSION

face plate. Fig. 20 is still another form in which both armature and field currents are carried by face plates.

MAGNET SWITCH CONTROLLER

The latest form of controller for many kinds of work is the magnet switch type used in suitable combinations. Fig. 21 shows the early form of a switch of this type arranged for machine tool work, and Fig. 22 shows the combination arranged for elevator service. It is interesting to note in this connection that a magnet switch was designed in 1892. This is a striking example of the abandonment for years of a principle which is later found to be best. In different cases this is due to different reasons; some times develop-

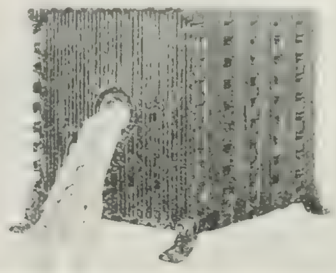

FIG. 28—EMBEDDED-TYPE RESISTOR

FIG. 29—BAR-TYPE RESISTOR

ments along other lines look more promising, suitable materials are lacking, etc. This brings out forcibly the fact that there must be a great deal of more or less negative experience, especially in a young industry.

RESISTORS

There have been a considerable number of interesting developments in resistors used in connection with controllers. Many different forms of construction have been used. The earliest form consisted of a resistance wire wound in a spiral and placed in tension, when suspended, to separate the turns. These would vibrate and come together and would sag under high temperatures. A very ingenious form of resistor

was developed about 1890. This was the so called cell type, a column of which is shown in Fig. 23. The resistance material consisted of ribbon instead of wire and the construction was such that the resistance ribbon could not sag or shift out of position under any kind of rough treatment or high temperature. This proved very effective and was used for many years. A later form in which there was more ventilation is shown in Fig. 24. At first these columns were mounted in cast iron housings, as shown in Fig. 25, but later the columns were used without any housings. This form of resistor was a markedly successful one and was used extensively for many years.

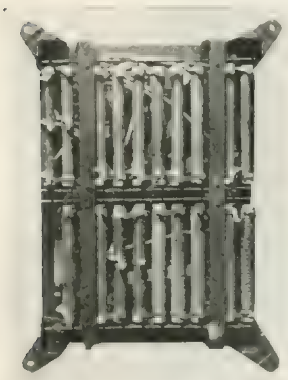

FIG. 30—TUBE-TYPE RESISTOR

The development of the cast grid for resistance marked an important step. Fig. 26 shows an early form of this kind of resistor. This was an excellent construction but rather expensive. Further development produced the present form of grid and mounting, shown in Fig. 27, which may be said to be nearly fundamental. In a completed frame 97 percent of the total weight is of iron which is the cheapest metal. About 80 percent of all the material is active as resistance and in the manufacture, notwithstanding the cheapness of the material, the total labor cost is less than a quarter of the material cost in the completed resistor. It is evident that there is not much opportunity for further reduction in cost as long as metals are used for resistance. The cast grid is not suitable for low currents, as there is a limit below which the cross-section of the material cannot be made and still retain sufficient strength. For small currents, therefore, it has been necessary to use other designs. For instance, imbedded resistors were used. These consisted of wire spirals imbedded in some form of cement or in sand, as shown in Fig. 28. A considerable degree of success was obtained with the use of these but it was found that a simpler form could be used. In the order given, the following types have been designed — the bobbin-type, shown in the controller of Fig. 20, the bar-type, shown in Fig. 29, the tube type, shown in Fig. 30, and the enclosed type, shown in Fig. 31. It is interesting to note that the later forms are the perfection in detail of those used in the very early applications.

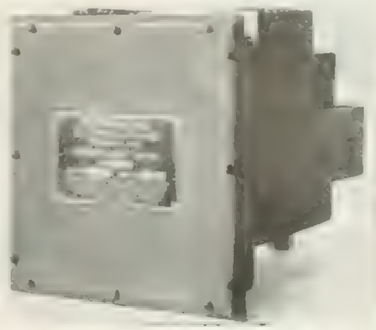

FIG. 31—ENCLOSED-TYPE RESISTOR

In the foregoing paragraphs only the high spots in the evolution of control apparatus have been pointed out. Outside of those who design and operate control apparatus it is not generally known how difficult, diversified and important the problems are. The writer, in closing, wishes to say to the credit of those who took part in the work in the past, as well as those now engaged in it, that their efforts deserve a prominent place in the whole field of electrical engineering achievement.

Control Panels for Synchronous Motors

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IT IS usual practice to equip panels for synchronous motors, with an oil starting switch or switches to connect the motor to the starting leads and line, and afford it the necessary protection from overload and failure of voltage; a field switch and the necessary rheostats for use in connection with the fields of the main motor and exciter (if a separate exciter is employed); and meter equipment to register the current, voltage, power-factor or kilowatt values, thus providing a check on the operation of the motor.

The type and capacity of starting switches or circuit breakers to be used for any given application are dependent on their current carrying and arcing capacities, as well as their ultimate breaking capacities. For motors of moderate size, with ordinary current and voltage conditions, a double-throw type of starter may be used. For large current and high voltages, it is necessary to use a starter consisting of a combination of circuit breakers, especially designed to withstand the more severe conditions, and having auxiliary arcing tips and heavy contacts to carry the current. In determining the ampere rating of the oil switch to be used, it is necessary to consider, in addition to the normal ampere rating of the motor, the starting current that will be required to start the load

to which the motor is attached. For starting a light load, such as a motor-generator outfit, it is possible to use a low voltage tap on the starting auto-transformers, with a consequent low starting current. The starter in this case, will not be required to handle as heavy an inrush of current as is encountered if the motor must start a heavy load, such, for instance, as a line shaft. In this latter case, the motor will probably be required to exert the maximum torque of which it is capable; the starting voltage will have to be high and the starting current will consequently be greater than when a low-voltage tap is used.

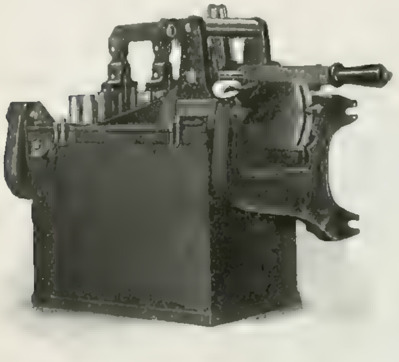

FIG. 1—A FOUR POLE, DOUBLE THROW STARTING SWITCH FOR SYNCHRONOUS MOTORS

There is always the possibility that a short-circuit may develop in the circuit beyond the starter, in which case it must interrupt a heavy current of a size dependent on the capacity of the generating station and synchronous apparatus on the line from which the motor is taking power and the reactance introduced by the lines and transformers. The starter must, therefore, have an ultimate breaking capacity which will be equal to the short-circuit current it must interrupt should a short-circuit develop, unless the feeder circuit breaker and relays are so set as to give selective action; in which case the motor starting switch or circuit breaker will have a definite time limit relay or an inverse time limit relay with a definite minimum limit, and the feeder circuit breaker will have an inverse time limit relay. The motor starter will then take care of a sustained overload, while the feeder circuit breaker will open under the more severe conditions imposed by a short-circuit.

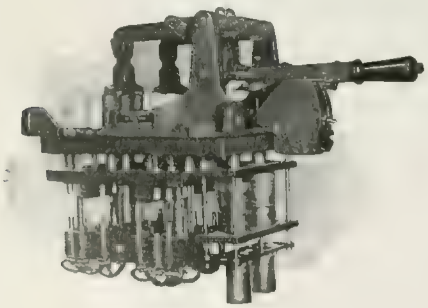

FIG. 2—SWITCH SHOWN IN FIG. 1 WITH OIL TANK AND WALL BRACKETS REMOVED

Of the two general classes of starting switches used for this service, the first consists of a four-pole double-throw oil circuit breaker, with a single handle which, when in one position, connects the motor to the line through the starting auto-transformer and, when in the other, connects the motor directly across the line and disconnects the auto-transformers, as shown in Fig. 3.

The double-throw starting switch is arranged for mounting directly on the panel, but remote control can be used if considered desirable by reason of high voltage or for other reasons.

The combination circuit breaker type of starter consists of one or two non-automatic starting circuit breakers and an automatic circuit breaker, of a number of poles to suit the phases of the circuits from which the power is obtained, mounted on a self-supporting pipe frame-work with handles on the front of the panel connected to the individual circuit breakers by suitable levers and connecting rods. When two starting circuit breakers are used, they are operated in tandem from a single handle. The handle of the starter is interlocked mechanically with the handle of the running circuit breaker, so that the starting handle must be closed, before the running handle can be closed. The closing of the starting handle connects the motor to the line through the starting auto-transformers and the closing of the running handle connects the motor directly to the line, disengaging the starting handle and disconnecting the starting auto-transformer exactly as with the double-throw switch.

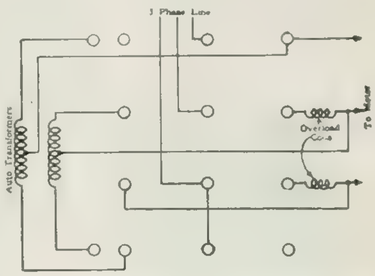

FIG. 3—DIAGRAM OF CONNECTIONS FOR SWITCH SHOWN IN FIG. 1

The connections shown are for three-phase but the same switch can be connected for two-phase operation.

Overload protection is provided by means of trip coils which, for large current or high voltages, require current transformers. To keep the switch from tripping out on ordinary overloads, such as the momentary rush of current at starting, a time limit of the dashpot or disc type is introduced, the time interval varying inversely with the load. Either starter trips independently of its handle so that it cannot be held

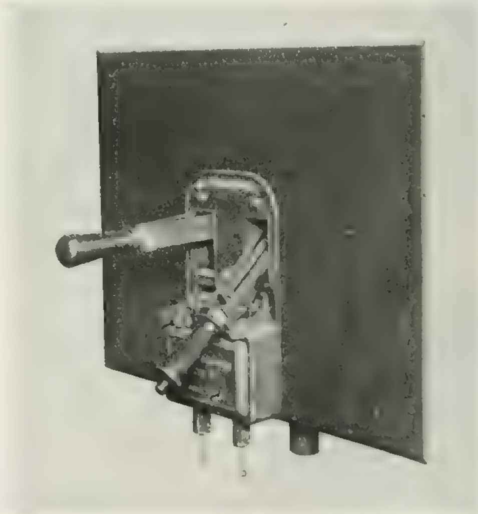

FIG. 4—DOUBLE-THROW CIRCUIT BREAKER TYPE OF STARTING SWITCH

closed in case of a heavy overload or short-circuit. Low voltage protection can be provided by adding a low voltage release attachment with a potential transformer for the higher voltages.

During the starting of a synchronous motor it is necessary to have the field circuit closed on itself, as otherwise a voltage will be induced in it by the transformer action, so high in value that the field insulation may be affected. When the motor is excited from a separate source of power, this is provided for by connecting in the field circuit a two-pole double-throw field switch, having its two lower studs short-circuited. While starting, the field switch is connected across the short-circuited studs, but as soon as the motor reaches full speed as an induction motor, the switch is thrown over so as to excite the motor fields.

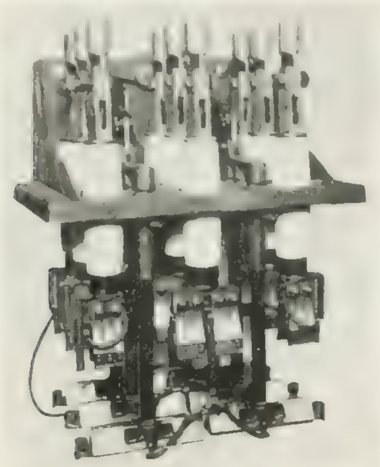

FIG. 5—REAR VIEW OF SWITCH SHOWN IN FIG. 4

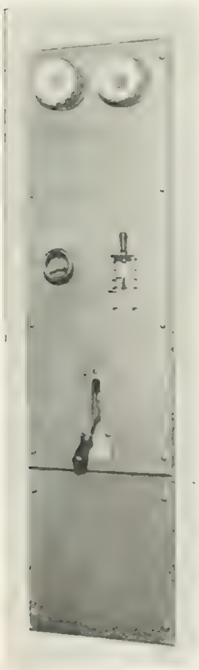

FIG. 6—STARTING PANEL FRONT VIEW

Showing meter equipment (field and main line ammeters), rheostat handle, field switch and main starting switch.

For motors equipped with individual exciters, the field switch is not required, as their fields can be connected directly to the exciter armature and field rheostat. The field is thus short-circuited by the exciter armature at starting and its excitation is gradually increased as the motor speeds up.

Provision for the motor and exciter field rheostats is made by two concentric hand wheels on the panel, one of which operates the exciter rheostat, ordinarily mounted on a tetrapod back of the panel, and the other operates the motor field rheostat through a chain and sprocket. In some cases where the exciter is designed especially to meet certain definite operating conditions the motor rheostat can be omitted. For instance, when a motor is to be applied to a mechanical load and will operate at practically unity power-factor at all times, or when a machine is to operate as a synchronous condenser and give a maximum corrective effect at all times, very little change in excitation is required, and this only to meet change in load or change in power-factor on the motor or condenser respectively, so that the field regulation can be furnished by the exciter. An exciter for this service is designed to give stable operation at the low voltage which may be required by this necessary regulation.

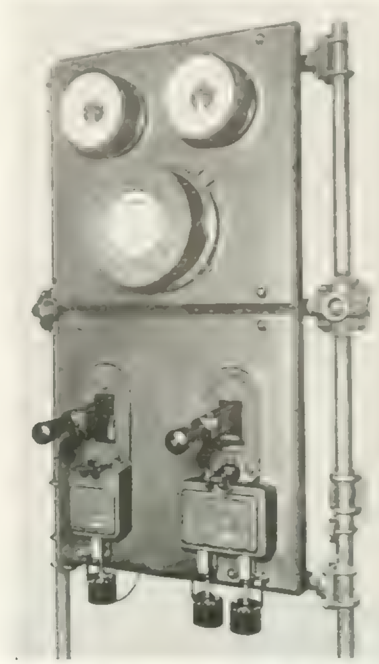

FIG. 7—WESTINGHOUSE STARTING PANEL OF THE COMBINATION CIRCUIT BREAKER TYPE

FIG. 8—REAR VIEW OF PANEL SHOWN IN FIG. 7
Showing mounting and location of circuit breakers.

The meter equipment needed is determined by the application of the motor and the operating conditions. For motors driving mechanical loads only, it is generally desirable to furnish an alternating-current ammeter to indicate the total armature current and a field ammeter to indicate the exciting current. These

meters will give a general indication of the thermal condition of the windings and will afford a means of knowing how nearly the operating conditions approach the limitations of the motor with which they are to be used, so that under ordinary conditions they are all that are required. If the motor, in addition to carrying its mechanical load, is used as a synchronous condenser, it is usually desirable to furnish a power-factor meter so connected as to indicate the power-factor of the system. Indicating wattmeters, reactive-factor meters, voltmeters, watt-hour and other meters can be furnished to meet the requirements of particular operating conditions. An indicating wattmeter may be used to show what portion of a load is being carried by the motor when it is used to assist an engine or other prime mover. A reactive-factor meter will indicate the reactive k.v.a. furnished by the motor to compensate for the low power-factor loads of induction motors or other inductive loads. If the motor is to be used partly or wholly as a condenser, with a sufficient amount of reactance in the line, it serves to regulate the voltage or improve the regulation of the line, and in this case a voltmeter will indicate whether it is furnishing the proper amount of reactive kilovolt-amperes.

Control for Mine Hoists

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THE SUCCESS of an electric hoist depends not only upon the type of motor used, but to a large extent upon the type and arrangement of control. Mine hoists are operated by both alternating and direct-current motors, there being particular fields for each.

GRAHAM BRIGHT

ALTERNATING-CURRENT HOIST MOTORS

The alternating-current motor is used for hoists of any size, except the very largest. The three-phase, 60 cycle, 440 volt, wound-rotor motor is best adapted for hoists of small and medium size, and 2 200 volt motors for the medium and larger sizes. For motors up to 100 horse-power, drum-type controllers are generally used. For motors larger than 100 horse-power, a magnet switch type of controller gives better satisfaction, since the repairs are excessive on drum type controllers. The manual labor necessary to operate a large drum controller is also a detriment to the use of this type for motors larger than 100 horse-power. For low voltage motors under 100 horse-power the drum controller will handle satisfactorily both primary and secondary currents; but for all high-voltage motors and the larger low-voltage motors, the primary of the alternating-current motor is controlled by magnet switches arranged for reversing. Oil switches were formerly used in the primary circuit, but it has been found inadvisable to use oil switches where the frequency of operation is greater than once every ten minutes. With magnetic control, the number of secondary switches depends upon the size of the motor, fewer switches being necessary for the smaller motors. The magnet switch controller is particularly adapted to very high-speed cycles where the hoist is stopped by reversing the motor. The writer has observed a hoist operating with a 300 horse-power motor from a depth of 330 feet with the following cycle:—Acceleration six seconds, constant speed four seconds, retardation three seconds, the maximum rope speed being 1 200 feet per minute. With a drum type controller this high-speed operation could not be kept up owing to the effect on the muscles and nerves of the operator.

A magnet switch control panel for a 250 horse-power, three-phase, 60 cycle, 440 volt hoist is illustrated in Fig. 1. The individual switches are simple and rugged and easily accessible for inspection and repairs. Limit switches are provided to prevent overloading due to careless operation of the master controller. The master controller is mounted on the hoist platform near the operating position and carries only the control circuits of the magnet switches. For the larger hoists, a voltmeter and ammeter are frequently added and prove of great assistance to the operator. Fig. 2 shows the diagram of connections, the oil circuit breaker being provided with no-voltage and overload release. After the no-voltage release or overload trip has operated, the master controller handle must be returned to the "off" position before the primary switches can be closed.

Safety Devices—Safety devices are essential for the successful operation of a mine hoist, and the electric hoist lends itself to the application of safety devices much better than a steam hoist. As before mentioned, the main oil circuit breaker is provided with both overload and no-voltage release which will open the main circuit to the motor in case of overload from any cause or failure of power. Some method must be provided to stop the hoist automatically if the circuit-breaker should open. This is accomplished by means of a brake magnet (indicated

in the wiring diagram, Fig. 2) connected across one of the phases on the motor side of the circuit breaker which when energized holds up a weight. When power is cut off from the magnet, the weight drops, tripping a latch which holds a larger weight. This weight is connected to the brake system so that when

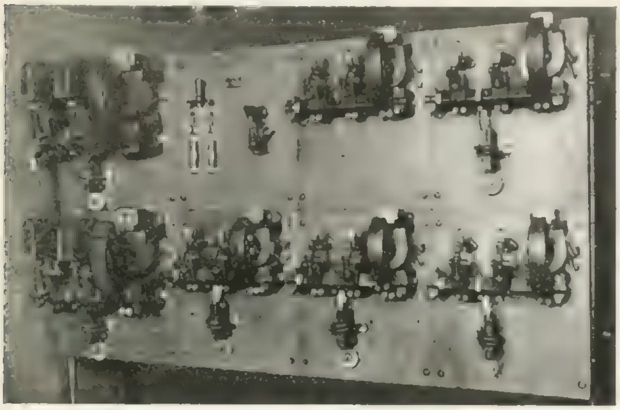

FIG. 1—CONTROL PANEL FOR A 250 HORSE-POWER HOIST MOTOR

the weight drops the brakes are applied. From the above it will be seen that the emergency brakes will be applied if there is failure of power from any cause.

In hoisting there is always the danger of the operator misjudging or forgetting to turn power off soon enough, resulting in the cage running into the head sheave and wrecking the hoist. A geared limit switch can be provided, as shown in Fig. 2, geared to the main drive, which will open the main circuit breaker if the cage travels a certain distance beyond the landing stage. This is generally accomplished by short-circuiting, or opening the no-voltage release circuit. Very often the head sheaves are only a short distance above the landing stage so that it would be impossible to stop the hoist if the cage were to reach the landing stage at full speed. Consequently the geared limit switch would be of little value unless a positive slow down can be obtained which will insure the cage running at a comparatively slow speed when arriving at the landing stage. This can be accomplished by providing extra contacts on the geared limit switch which will cause all secondary switches to open at a predetermined point in the shaft, inserting the total resistance in the secondary circuit and causing the hoist to slow down. If the cage should happen to overwind, the second set of contacts on the geared limit switch will open the main circuit breaker and stop the hoist by means of the brake magnet.

With unbalanced hoisting, or lowering loads, where the motor is running above synchronous speed and is returning energy to the line, this type of geared limit switch may cause trouble, since introducing resistance into the secondary will cause the speed to increase instead of decrease. For such cases a more reliable geared limit switch is furnished by some hoist builders along the line of the Welch safety device for steam hoists. This consists of an ordinary fly-ball governor which is connected to a geared limit switch in such a manner that if the speed is above a certain value at a certain predetermined point in the shaft, the main circuit breaker will be opened and the brake applied. This device can also be used to prevent too high a rate of acceleration. Its operation depends entirely on speed and is independent of the load. If the operator starts up too fast or forgets to slow down at the proper time, this geared limit switch will operate and stop the hoist. A rule which should always be applied to the design of safety devices is that electric current should never be depended upon to operate the device, but that the device is to depend on the opening of a circuit or the failure of a circuit. The brakes depend on gravity which is much more reliable than electric power or compressed air. A geared limit switch should always be arranged so that in case the hoist overwinds it will then be impossible for the operator to start the hoist in the wrong direction. Hatchway limit switches may also be provided, which work from the cage itself and not from the drum.

A very popular method of controlling alternating-current hoist motors is by means of a liquid rheostat in the secondary, the primary being controlled by magnet switches. The liquid rheostat has the advantage of simplicity, low cost, low maintenance and smooth acceleration. Automatic acceleration is produced by controlling the flow of the electrolyte in the

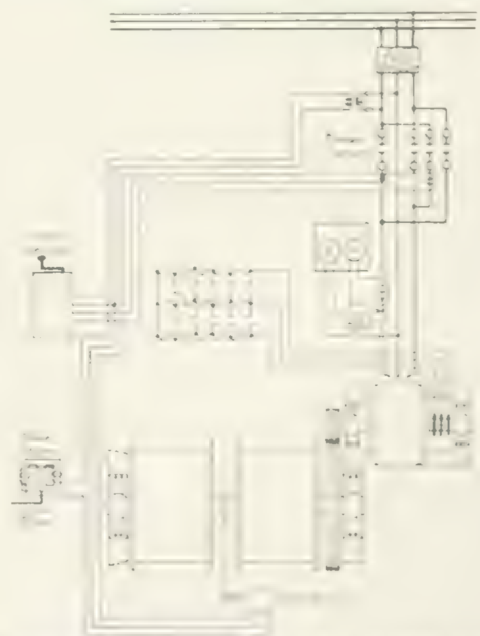

FIG. 2—DIAGRAM OF CONNECTIONS FOR A HOISTING OUTFIT DRIVEN BY AN ALTERNATING-CURRENT MOTOR

heavy duty type and using a dashpot in the light duty type. The heavy duty type has had frequent applications in this country, while the light duty type has been largely confined in its application to European countries. The liquid rheostat is particularly well adapted to large hoist motors since the size and num-

ber of the secondary switches and resistors make the cost of the magnetic control prohibitive.

DIRECT-CURRENT HOISTS

For direct-current hoists of small and medium sizes, series or compound motors are generally installed. A drum controller can be used up to about

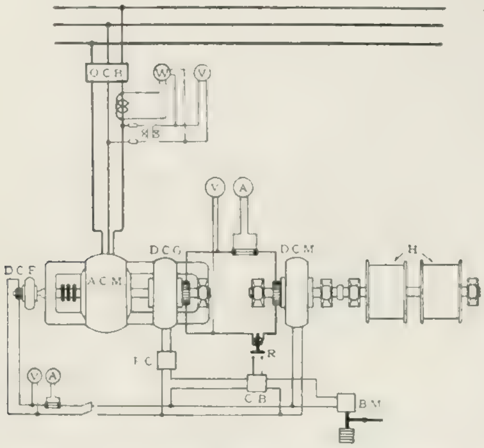

FIG. 3—DIAGRAM OF CONNECTIONS FOR A HOISTING OUTFIT DRIVEN BY A DIRECT-CURRENT MOTOR

100 horse-power, 250 volts, and 200 horse-power, 500 volts, above which magnetic switch control should be used. Dynamic braking can easily be applied when stopping or lowering unbalanced loads. Where the load is liable to overhaul the winding drum a series or compound motor is unsafe, as dangerous speeds may easily be attained.

For the larger hoists, when high speed and frequent service is desired, the Ward-Leonard or the Ilgner system should be used, depending on the condition of the power system. In the Ward-Leonard system, the hoist motor is a direct-current, separately excited motor, taking its power from a separately excited generator which is in turn driven by a synchronous or induction motor. The exciter supplies a constant voltage for all the fields. The controller handle has a central position and a movement in a forward or reverse direction will cause the hoist motor to operate in the direction desired. A reference to the diagram of connections, Fig. 3, will show that the armature in the generator of the motor-generator set is connected electrically to the armature of the hoist motor, and the motor for driving the set is connected to the line through the usual protective devices.

The operation of the equipment is as follows:—When the hoist motor is in the "off" position, no current is flowing through the generator field and consequently no power is delivered to the hoist motor. The hoist motor is, however, continually excited, and during operation the direction or strength of the motor field is not changed. When the field controller is moved either to one side of the neutral or the other, the generator field is excited, the strength of the excitation depending upon the movement of the controller lever. As the generator is excited, the armature voltage will increase and the hoist motor will revolve in either one direction or the other, depending upon the direction of the generator field excitation. The speed at which the hoist motor runs is practically proportional to the armature voltage of the generator. The only rheostatic loss when starting the hoist motor is that in the field controller of the generator, but as the current flowing through the field circuit is very small in proportion to the armature circuit, the loss is negligible. One of the most important advantages of this arrangement is that it is possible to run the hoist at any speed from zero to the maximum without rheostatic loss, and at the same time it is possible to handle the largest equipment met with in practice without interrupting the main circuit. The speed at which the hoist motor runs is practically independent of the load, and depends only upon the voltage across the armature of the motor. When it is necessary to lower loads, the speed can be controlled by electric braking, as the motor in this case operates as a generator and supplies energy to the motor-generator set, which returns power to the line. Whether the load is being hoisted or lowered, the speed is practically proportional to the throw of the controller handle. If the hoist is retarded at a quicker rate than would be the case if it would drift, electric braking automatically takes place, the energy being returned to the motor-generator set. The rheostatic losses are, therefore, not only avoided when starting, but also when braking. When the handle of the controller is turned to the "off" position, electrical connection is made from the armature of the generator through its shunt field in such a manner as to buck the residual magnetism. This is done in order that time may be saved in building up the field in the reverse directon should it be desired to reverse

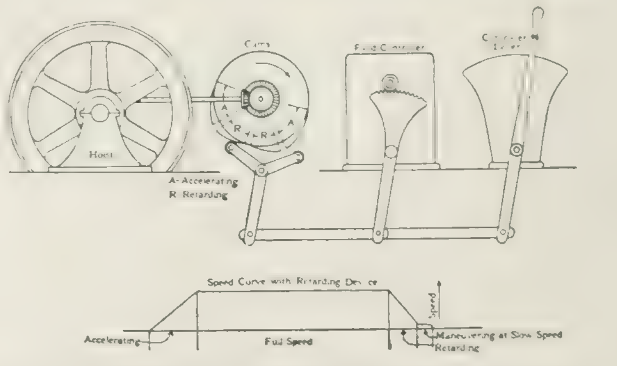

FIG. 4—ARRANGEMENT OF CAMS AND LEVERS FOR RETARDING THE HOIST AUTOMATICALLY

the motor, and to prevent idle currents from flowing through the armature circuits due to the voltage generated by this residual magnetism. This current may amount to 65 percent of full-load current and will cause considerable heating as well as a tendency to creep.

Retarding Device—The Ward-Leonard system lends itself very nicely to the application of a very simple and rugged slow-down device. From the de-

scription of the operation of the equipment, it will be seen that the speed at which the hoist motor runs is practically proportional to the armature voltage and the resistance steps of the field controller are so arranged that the throw of the controller handle is practically proportional to the speed. A simple arrangement of cams with the necessary operating levers for connecting the controller handle makes it possible to retard the hoist automatically as it approaches the surface. Referring to Fig. 4, it will be seen that the raised portion of the cam, which is brought under the roller *A* as it approaches the surface, causes the controller lever to be brought to the "off" position, and the rate at which the lever moves is controlled by the curvature of the cam. As it makes no difference, so far as speed is concerned, what load there is on the hoist motor, it will be seen that this provides a positive arrangement for slowing down the hoist under all conditions as the cage approaches the surface. If the load is being lowered and the hoist motor is being run as a generator, its speed still varies with the throw of the controller lever, so that the motor slows down independently of the mechanical brakes.

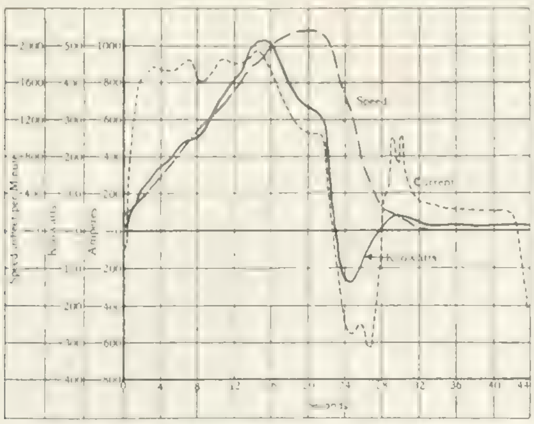

FIG. 5—HOISTING CURVES, SHOWING OPERATION OF RETARDING DEVICE

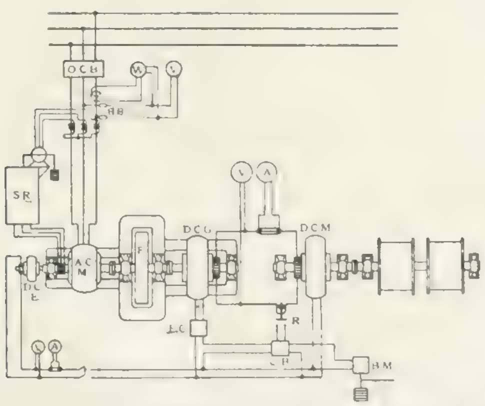

FIG. 6—DIAGRAM OF CONNECTIONS OF THE ILGNER SYSTEM OF HOISTING

The cams are so arranged that, when starting, the thow of the controller is limited and the starting current is regulated independently of the operator. As the hoist motor accelerates, the throw of the controller can be increased until full speed is gradually attained. This device is extremely simple in its action and has an advantage over the usual safety device in that it is used every time the hoist is operated and is therefore always in a serviceable condition. The construction of the cams, their driving mechanism and their connecting levers and rods depends upon the construction of the hoist, and the controller is so arranged that it can be connected up very readily in the manner shown in Fig. 4. Fig. 5 shows the results of tests made on equipment under various operating conditions and indicates how the hoist was brought to the rest position independently of the operator. It will be noted in these tests that the mechanical brakes were not applied, but that the controller lever was brought to such a position that only sufficient current flowed through the armature to balance the load due to the hoist. These tests were made by bringing the hoist to full speed and allowing it to come to the rest position without any attention whatever from the operator. Although this accelerating and retarding device has not been used to any great extent in the United States, a large number are in successful operation in Europe.

Overload Protection—An overload relay is provided in the armature circuit, which operates a circuit breaker in the generator field. This circuit breaker is of the two-pole type, one pole of which opens the generator field and the other opens the brake magnet circuit. If the hoist is overloaded, the excitation is cut off from the generator, and at the same time, the armature of the brake magnet falls, causing the main brakes to be applied. If, for any reason, (such as the cage being stuck or careless operation) an excessive overload is thrown on the machines, current will be cut off and the brakes applied independently of the operator. This circuit breaker is located close to the operator, so that the circuits may readily be reëstablished when the overload conditions are removed. The circuit breaker can also be tripped by hand, so that it can be used to operate the emergency brakes in case some obstruction prevents the free movement of the controller. If the exciting circuit for the hoist motor is interrupted, the brakes are applied and the excitation of the generator is shut off. The brake magnet has a capacity of 100 inch-pounds and a travel of 1.5 inches. It can be used to operate either an exhaust valve in the case of air-operated dead weight brakes, or a latch in the case of dead weight emergency brakes.

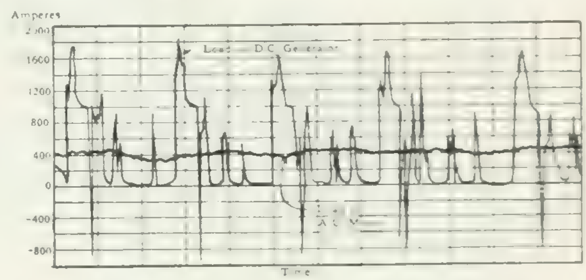

FIG. 7—RESULTS OF TEST ON THE ILGNER SYSTEM

The Ilgner system is an extension of the Ward-Leonard and is used where it is desired to keep peak loads off the power system. The extension consists of the addition of a flywheel and slip regulator, the flywheel absorbing or giving up power through the action of the slip regulator, which is connected in the secondary of the alternating-current motor. This motor is usually much smaller than would be necessary when using the Ward-Leonard system.

As shown in Fig. 6, the motor for driving the set is connected to an incoming line through the usual protective devices, the rotor circuit being connected to the automatic slip regulator. The exciter supplies a constant voltage for exciting the generator and hoist motor. The operation of the equipment is as follows:—Assuming the set is running at full speed and the field controller is in the "off" position, the hoist motor will be at rest, as there will be no current flowing through the armature circuit; the motor, however, will be fully excited. If the generator field is gradually excited, the voltage of the armature circuit will increase and the hoist motor will start to revolve, its direction depending upon the direction of the generator field excitation. At the start, the load of the generator is greater than the average over the hoisting cycle and the automatic slip regulator enables the flywheel to supply the difference between the average generator input, which is carried by the induction motor, and that necessary when starting. The automatic slip regulator is so arranged that when the current in the primary circuit of the induction motor exceeds the average value, the resistance is automatically inserted in the rotor circuit, so as to enable the speed of the set to decrease and a portion of the energy in the flywheel to be given up. The rate at which the speed in the set is decreased depends upon the difference between the input of the generator and that required when starting. When the load of the generator decreases below the average, the operation of the regulator is reversed and the difference between the output of the induction motor and the input to the generator is stored in the flywheel, the speed of the set being thereby increased. A voltage regulator is supplied, which automatically maintains the voltage of the exciter constant, independent of the speed. This equipment enables the input to the hoist to be maintained practically constant at the average value regardless of the peak load of the hoist when starting. The large fluctuation which takes place on the hoist motor and the correspondingly small fluctuation which takes place on the power system is shown in Fig. 7. One of the most important advantages of this arrangement is that it is possible to run the hoist at any speed without rheostatic loss and, furthermore, the speed will remain practically constant, independent of the load or position of the cage in the shaft. When it is necessary to lower loads, the speed can be controlled by electric braking, as the motor in this case operates as a generator. and supplies energy to the direct-current machine of the flywheel set. This causes energy to be stored in the flywheel and after the speed of the set reaches a value slightly above synchronism, energy may be returned to the line. If the armature voltage is reduced at a quicker rate than the speed of the motor would decrease if it was allowed to drift, electrical braking automatically takes place, the energy being returned to the flywheel. Fig. 8 illustrates a 1 000 kw flywheel motor-generator set, which supplies power to a 1 200 horse-power direct-current hoist motor.

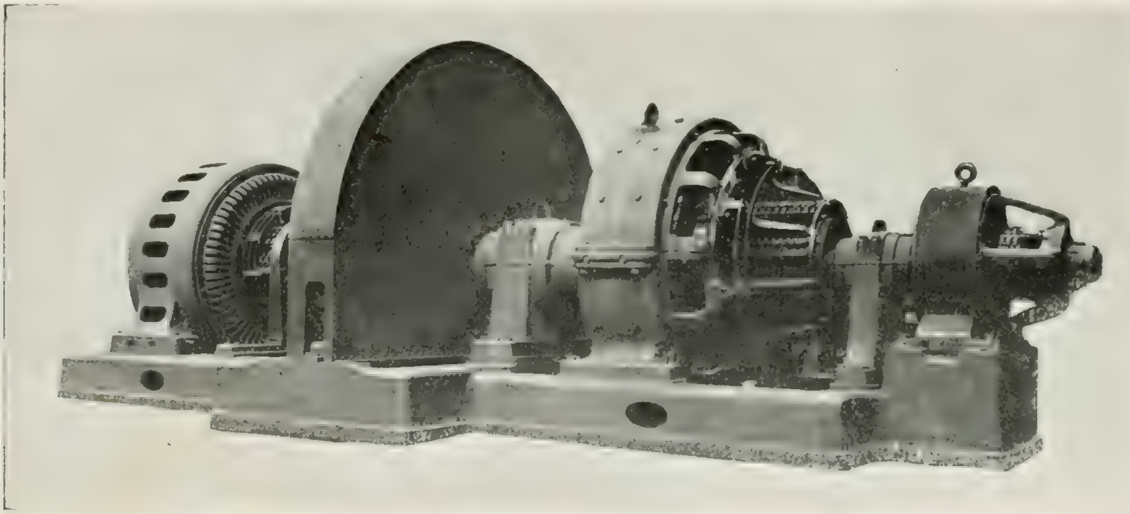

FIG. 8—WESTINGHOUSE FLY-WHEEL SET FOR A HOIST MOTOR

The field controller generally consists of a large face-plate controller, but for the larger hoists, magnet switches can easily be substituted and a master controller supplied. The use of magnet switches permits of the use of current relays which will prevent the hoist motor from being overloaded by careless operation of the controller by keeping the accelerating current down to a definite maximum value.

The Control of Induction Motors for Rolling Mill Drive*

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IT IS the intention in this article to deal only with the control of large induction motors driving main rolls and to briefly review the requirements of such controllers. The functions of the controller are to start the motor properly so as to protect it during the starting period, and also to maintain the current at a minimum value consistent with the required starting conditions; to protect the motor properly during operation; to insure that the motor operates under the best conditions for the mill, motor and power supply.

WILFRED SYKES

Due to the large inertia of the rotating parts of the mill drive, it is very easy to overload the motor during the starting period, and for this reason, it is customary with larger machines to provide automatic acceleration by which the current is limited to a predetermined value. This makes it impossible for a careless operator to cause any injury to the apparatus. This scheme presents no particular advantage over a manually operated controller where careful attendants are employed and where the motor is started from the controller panel. In a number of cases, therefore, simpler controllers have been used, consisting of switches mounted on a panel, which cut out steps of the resistance. A controller of this type for starting rolling mill motors is shown in Fig. 1. The first ten switches, in this case, are single pole and they cut out sections of the resistance in alternate legs. The last three switches are double pole and are used for running positions. By making the switches double pole, the resistance during running is balanced; consequently the divisions of the rotor current are equalized. A controller of this type is provided with an ammeter and two oil circuit breakers, one for the forward running position and one for the reverse. The resistance switches and the oil circuit breakers are all mechanically interlocked so that they can be operated only in the correct sequence. This type of control is extremely simple and, for cases where remote control is not required, has proven very satisfactory. The absence of all electrical interlocks and the small number of parts make such a controller very desirable from an operating standpoint.

The secondary switches of such a controller for automatic acceleration and remote control are shown in Fig. 2. These switches are all of the two-pole type closed by an alternating-current magnet, each switch being provided with its own accelerating relay. Their operation is controlled by a master switch with the same number of points as there are switches. The last two or three switches to be closed may be used as running points to insert various amounts of resistance in the rotor circuit. The individual switches may be closed one at a time from the master switch, or the latter may be placed in the "full-on" position and their operation will be controlled by the accelerating relays. These relays limit the current between certain definite values during the starting period, these values being, of course, adjustable to existing conditions. The object of using individual relays is to simplify the controller, avoiding all interlock wiring and the multiplicity of small contacts which were common in some of the early controllers.

G. E. STOLTZ

The primary control consists simply of a feeder panel with the necessary instruments and oil switches for the running and reversing positions. These oil switches may be hand operated or electrically operated, depending upon their location with respect to the master switch. When motors of more than one speed are used, it is customary to arrange the pole changer in the form of a drum switch. This is much more compact and is a simpler arrangement than would be the case if magnetic switches were used for this purpose, and as the speeds are not as a rule changed during operation, there is no necessity for making the pole changer automatic to be controlled by the master switch. In some cases this has been done, however, a small motor being used to revolve the drum.

An entirely different type of secondary control for rolling mill motors is shown in Fig. 3. This controller is of the liquid type and is arranged for automatic acceleration and for regulating the speed, if required, during operation. Fig. 4 shows diagrammatically the construction of this controller. The motor, which is

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*From a paper presented at the eighth annual convention of the Association of Iron and Steel Electrical Engineers, Cleveland, Ohio, Sept. 14-19, 1914.

shown mounted on the tank, is an ordinary induction machine, which is connected to the line through a three-phase, series transformer, the current flowing through the windings of the motor being proportional to the current in the line. The motor slip rings are connected to three fixed electrodes at the bottom of the three earthenware pots shown in Fig. 3. Directly above these fixed electrodes are three moving electrodes which are electrically and mechanically connected together and which are supported from the arms mounted on the motor shaft. At the opposite end of the arms, counterweights are provided which practically counterbalance the weight of the moving electrodes. The torque motor is so connected that it has a tendency to revolve in such a way as to raise the moveable electrodes. At normal full-load current the torque

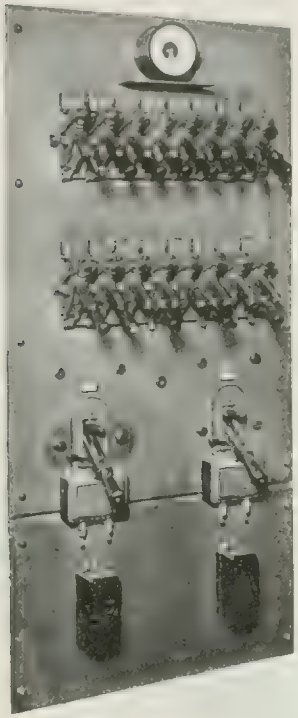

FIG. 1—MANUALLY OPERATED CONTROL FOR ALTERNATING-CURRENT ROLLING MILL MOTORS

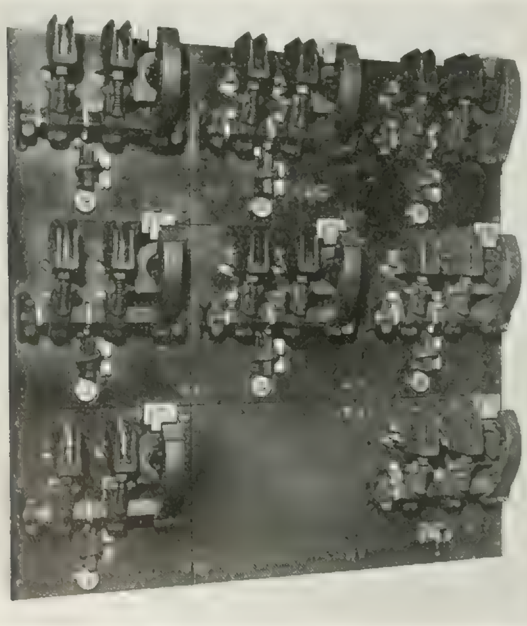

FIG.—2 MAGNET SWITCH CONTROL FOR ALTERNATING-CURRENT ROLLING MILL MOTORS

of this motor plus that due to the counterweights, is just sufficient to balance the weight of the moving electrodes. An increase in the current will upset this balance causing the electrodes to separate, or a decrease will allow them to approach the fixed electrodes. Before the motor is started, the moveable electrodes are held in the highest position. When they are released they will approach the fixed electrodes until the current reaches the value at which the torque

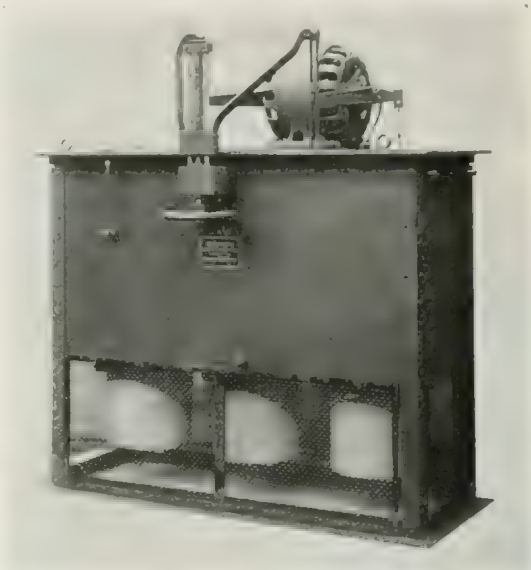

FIG. 3—AUTOMATIC SLIP REGULATOR FOR CONTROLLING THE SECONDARY OF AN ALTERNATING-CURRENT ROLLING MILL MOTOR

of the motor plus that of the counterweights just balance the weight of the electrodes. The motor in the meantime is accelerating and the rotor current has a tendency to decrease so that the moving electrodes tend to fall. Any decrease in the distance, between the electrodes, however, causes a reduction in the resistance and consequently the electrodes fall at such a rate as to maintain the balance mentioned above. In this way automatic acceleration is provided for, the current being maintained at practically a constant value during the whole starting period. The primary control used with a liquid starter is the same as that for the ordinary magnet switch controller.

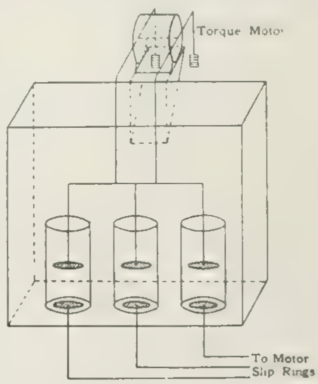

FIG. 4—DIAGRAMMATIC SKETCH OF AUTOMATIC SLIP REGULATOR

Particular attention is drawn to the simplicity of the three controllers mentioned. The difference between these controllers and those that were commonly used a few years ago for large rolling mill motors is very marked. It is believed that more difficulties have occurred in rolling mills due to complicated controllers than to faults in the motors, and for this reason, modern practice aims at simplicity, preserving at the same time the desirable features of the older types. The entire absence of interlocks with a multiplicity of contacts is a great step forward and avoids many of the difficulties encountered with the other controllers. This question of simplicity in controllers is of such importance that particular attention should be drawn to it

and, in new layouts, the avoidance of automatic operation, remote control and all features that can just as well be hand operated, should be given careful consideration. It is possible to do almost anything with controllers in the way of automatic control and remote operation, but the desirability of such arrangements for steel mill work is questionable. In cases where it is necessary for a skilled control engineer to spend several days in order to straighten out interlock wiring, relay operation, etc., it is obvious that such a controller must have many points of weakness and must eventually lead to trouble. The motors for driving mills have been brought to such a state of perfection that, except under extraordinary conditions, trouble seldom occurs, and the aim now should be to so simplify the controllers that they will be as reliable as the motors. Unfortunately this cannot be said of the majority of controllers supplied in the past.

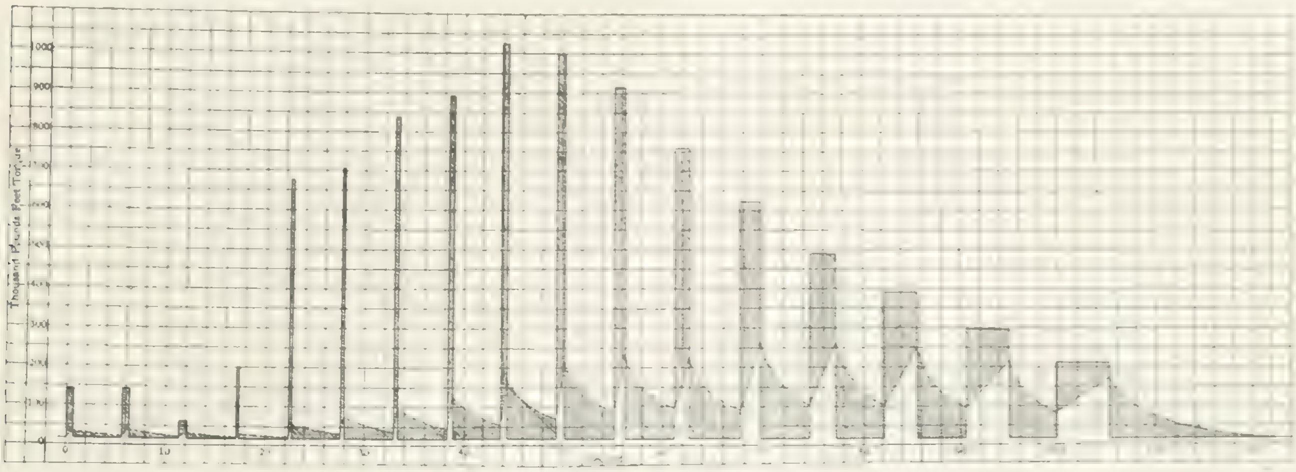

FIG. 5—THEORETICAL LOAD CYCLE OF A MILL MOTOR

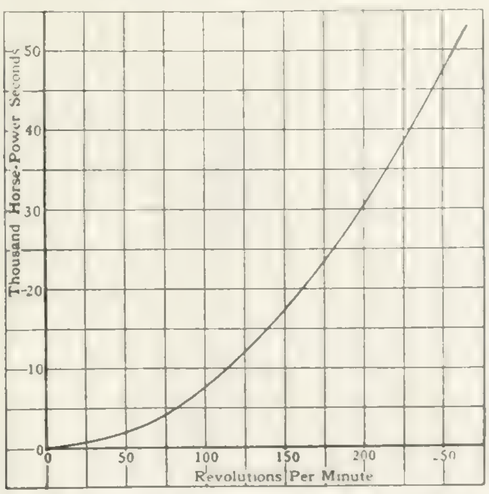

FIG. 6—CURVE SHOWING THE DEVELOPMENT OF STORED ENERGY IN THE FLYWHEEL WITH INCREASING SPEED

For the protection of the motors during starting and operation, overload and no-voltage relays are usually provided on the circuit breaker. In addition, instruments are provided so that the load on the machines may be noted and any extraordinary conditions that arise can readily be controlled. In the case of the overload protection, it is usually impossible to set the relay at such a value as to protect the motor from long continued overloads of a moderate amount, as the circuit breaker should only come out in the case of an overload of such an amount that the motor is likely to be injured in a few moments. Rolling mill motors must carry high momentary peaks and it is difficult to protect them against overloads. Most of the motors, however, are arranged to withstand 25 percent overload continuously and, by proper attention to the instruments, little trouble is usually encountered due to the lack of such protection. To protect the mill properly, it is at times necessary to stop the motor rapidly, and in the past various schemes have been used for this purpose. In several instances the stator of the motor has been disconnected from

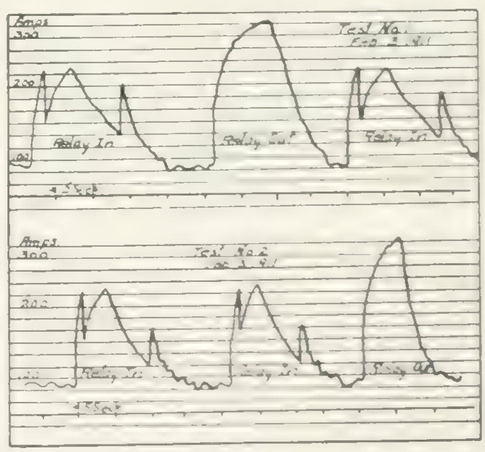

FIG. 7—CURVES SHOWING THE EFFECT OF MAGNET SWITCHES

the alternating-current circuit and excited with direct current, the rotor being connected across the resistance. The motor, in this case, acts as a synchronous generator, power being generated in the rotor which is dissipated in the resistance, and the motor is thereby brought to rest quickly. This arrangement is not altogether ideal as very careful adjustment is necessary to insure the maximum braking torque. It is possible to reduce the resistance to such a value that the braking torque is very small, but the scheme is not then effective. In addition, very great unbalanced

magnetic pulls are set up as the speed of the motor approaches zero, which can readily cause a springing of the shaft or striking of the stator on the rotor. In addition it requires a source of direct current which is not always available. Undoubtedly the most satisfactory method of bringing the motor to rest is to connect it to the line with the stator connections reversed, at the same time inserting the proper amount

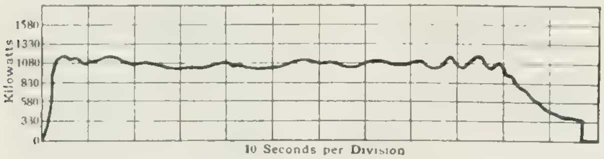

FIG. 8—STARTING CURVE WITH SLIP REGULATOR IN OPERATION

of resistance in the rotor circuit. The braking torque can then be regulated to any amount desired by adjusting the rotor resistance. The only disadvantage of this scheme is that at the moment the motor is reversed, double voltage and frequency are impressed on the rotor. This calls for extra insulation, but if this is provided there are no objections to the arrangement. As double voltage is impressed on the rotor, it is necessary to provide sufficient resistance to limit the current properly. If, for instance, the ordinary starting resistance limits its current at starting to full

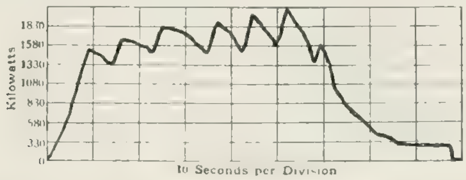

FIG. 9—STARTING CURVE, USING GRID RESISTANCE AND SWITCHES

load value, double this amount of resistance would be required when braking to hold the current to the same amount. Or, if the same resistance as in starting is used, the current that will flow will be double the full-load current, and this can be considered in its relation to the setting of the circuit breaker and to the capacity of the power house, lines, transformers, etc. The simplicity of this arrangement has much to recommend it and, although it somewhat increases the cost of the motor, yet the saving in the controller probably offsets this increased expense. The only

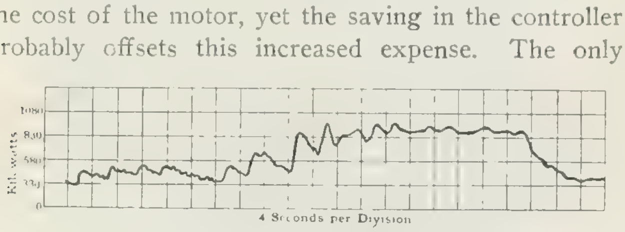

FIG. 10—OPERATING CURVE, ROLLING WITH AUTOMATIC SLIP REGULATOR

additional controller cost involved is that necessary to provide the extra resistance for the rotor circuit during the braking period and possibly an extra switch to short-circuit this resistance.

Practically all induction motors driving rolling mills operate in conjunction with flywheels which are intended to assist the motor during peak loads. It is a comparatively simple matter to limit the peaks on the motor when they are of short duration, but this is not always sufficient in rolling mill service as the length of peaks increases as the metal is elongated. The proper function of the flywheel is to deliver energy at such a rate during the periods of peak loads, that the load on the motor does not exceed the average value over the whole cycle. Such an ideal condition is never attained in practice, but with proper control this can be approximated. In order that the flywheel be able to give up energy during the period of peak loads, its speed must decrease. The ordinary induction motor decreases only about two or three percent from no load to full load, and if the flywheel were designed to take the peak load with such a small drop in speed, it would be of excessive weight. Such close speed regulation is not necessary in rolling mill service, and a variation of 10 to 15 percent, or more, can be allowed without difficulty.

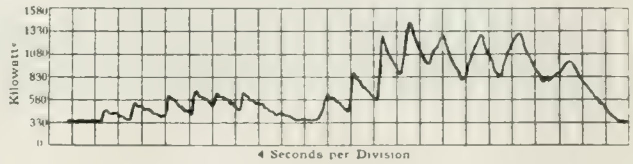

FIG. 11—OPERATING CURVES, ROLLING WITH 11 PERCENT SLIP

Resistance is inserted in the rotor circuit so that the speed of the induction motor will decrease a sufficient amount with increased load to enable the flywheel to be of economical size. The common practice is to insert from 10 to 15 percent resistance, which is left in the rotor circuit. The speed of the motor then decreases a corresponding amount with increased load and the flywheel delivers part of the energy stored in it. Unfortunately this does not give the best condition

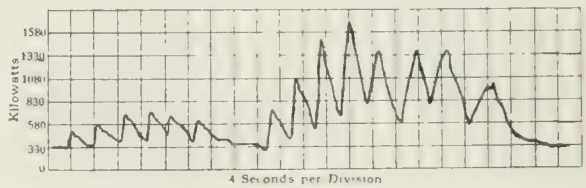

FIG. 12—OPERATING CURVE, ROLLING WITH SIX PERCENT SLIP

for load regulation on the motor. With such a scheme the load on the motor must be increased continually to enable the flywheel to give up energy, whereas, the ideal condition requires the load on the motor to be constant while the flywheel is giving up energy. Mr. H. C. Specht* developed a formula showing the relation between the torque delivered by the flywheel and that by the motor. According to this formula the load on the motor varies as a logarithmic curve, and for a fixed resistance it is not economical to attempt to cut off peaks of more than two or three seconds duration, as the flywheel effect required becomes excessive. To illustrate this type of control Fig. 5 shows a load cycle of a motor driving a plate mill on which, for simplicity, the interval between passes has been assumed as five seconds throughout. The full line represents the total

*In the Transactions of the American Institute of Electrical Engineers, June, 1909, p. 870.

power which, at all times, is equal to the sum of the motor and flywheel outputs. Between passes the flywheel output is negative. During this period the motor output is the sum of the friction load and the input of the flywheel. The dash line curve represents the motor load. The cross-sectional area above this line during the passes represents the load carried by the flywheel. The energy returned to the flywheel in bringing it up to speed between passes is graphically indicated by the cross-sectional area. In Fig. 6 is shown graphically the energy stored in the flywheel in this particular installation at various speeds. During the first portion of the passes it will be noted that the flywheel takes the greater portion of the load, its share decreasing with time. As the speed drops from 250 to 230 r.p.m., 7 100 horse-power-seconds are given up by the wheel. As the rotor continues to slow down from 230 to 210 r.p.m., 6 700 horse-power-seconds are available, as will be seen from Fig. 6. Thus, during the latter part of retardation, the motor load increases at a greater rate to compensate for the falling off of the flywheel output. To improve the operation in some way, controllers have been made by which the resistance, instead of being in circuit all the time, is cut in and out in one or, at the most, two steps by means of magnet switches. The operation of such a controller, as indicated in Fig. 7, illustrates what are probably the best results that can be obtained with a controller of this type. It will be seen that, although such an arrangement materially reduces the peaks, it does not, by any means, eliminate them.

Scaling the curve of the first test, the peak load, with relay in, is found to be 41 percent above the average. The friction load preceding the first pass, which is shown to be somewhat less than 100 amperes, has not been included with this average value, so that this figure represents the total load only during the heavy rolling period which starts with the first peak. The maximum load, with relay out, is 91 percent above the average load. On the second test the maximum peak, with relay in, is 48 percent in excess of the average, and with relay out, 104 percent. These curves indicate that the relay has been successful in reducing the peaks approximately 53 percent, but there yet remains an average peak of 44.5 per cent.

The automatic slip regulator, Fig. 3, already described, performs this function in an ideal manner. As a starter, its main function is to insert resistance automatically at such a rate as to maintain the output of the motor practically constant, drawing energy from the flywheel at the proper rate. If the current tends to increase above the setting of the regulator, the electrodes will be separated at the proper rate to maintain constant load on the motor. The setting of the regulator can be changed either by varying the taps on the motor current transformer or the amount of the counterweight, the latter being the usual arrangement if the range over which the set is to be varied is not too great.

Fig. 8 is a starting curve of a plate mill motor operating in conjunction with a liquid slip regulator. The latter automatically limits the load during the starting period to a practically constant value. The curve shown in Fig. 9 is a starting curve taken on the same motor and mill, the control consisting of grid resistance and switches. In order to obtain a fair comparison of the operation of the liquid regulator with another type of control, one was installed temporarily on a plate mill motor which operates with fixed resistance. Switches were placed in the secondary so that the motor could be connected either to the regulator or the resistance. The length of passes in rolling the plates varied from 0.28 of a second to four seconds.

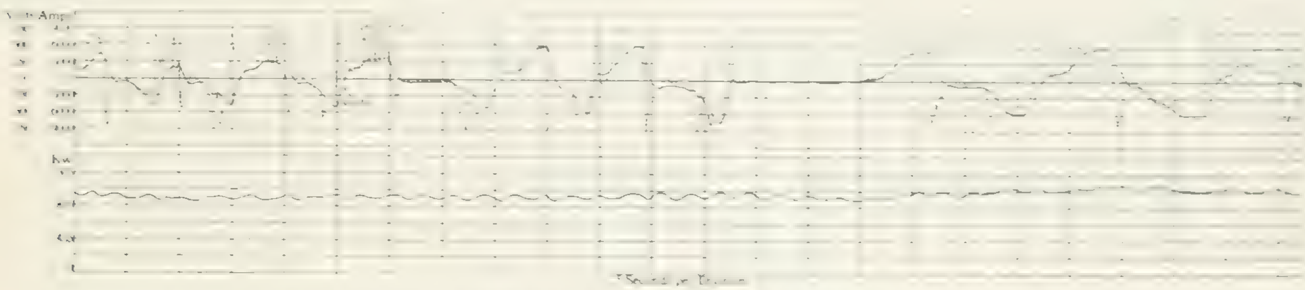

FIG. 13—CURVES SHOWING INPUT AND OUTPUT OF FLYWHEEL MOTOR-GENERATOR SET WHILE ROLLING ONE INGOT

Referring to Fig. 10, it will be noted that the first few passes are very light and do not rise to the value at which the regulator is set to operate. Beginning with the ninth pass, the average load is found to be 800 kw with a maximum peak of 980 kw. Theoretically, the motor load curve is a straight line, but practically it will deviate from this average value as shown on the curve, Fig. 10, which does not vary more than 11.1 percent from the average load during heavy rolling periods. Figs. 11 and 12 are graphic curves taken when rolling subsequent slabs on the mill, the rolling conditions being practically identical throughout the series of tests. The former curve was obtained when rolling with 11 percent fixed slip. The average input over the same period of heavy rolling is 1 008 kw and the maximum peak 1 420 kw, which is 41 percent above the average. The curve, as shown in Fig. 12, represents the load with a fixed slip of six percent. This average is 980 kw input, with a peak of 1 675, or 71 percent.

From the above figures, it is apparent that, should the motor be operated on the liquid regulator, the

capacity of the power plant could be 440 kw smaller than if a controller with 11 percent slip be installed. Should the slip be limited to six percent, an advantage of 695 kw in favor of the slip regulator is obtained. If the power house capacity were sufficient to carry the load under the latter condition, 930 hp additional load could be accommodated, if this controller should be replaced by a liquid slip regulator. Or, if the power plant is being operated at its full capacity with 11 percent fixed slip on the mill motor, 590 hp would be available for other purposes should the control be replaced by a liquid slip regulator.

An important feature of any regulator is the rapidity with which it responds to momentary peak loads. If no flywheel effect were available, the load would approach the theoretical condition shown in Fig. 5. The amount these peaks are reduced depends upon the character of the control as will be noted from Figs. 7, 10, 11 and 12. The regulator must respond almost instantly in order to catch the peak as the metal enters the rolls. Fig. 13 shows the result of tests made on a reversing blooming mill operated by a direct-current motor, which obtains its power from a flywheel motor-generator set. The alternating-current motor driving this set is controlled by a liquid slip regulator. The curve indicating the voltage and amperes is the output of the generator end of the set, while the smooth curve below is the input to the alternating-current end. Although the peaks are very short and of a highly intermittent character, the input to the alternating-cuirent end does not vary more than 11.5 percent from the average.

In selecting a control for any particular installation, all of the three functions outlined in the first paragraph should receive unbiased attention, but above all, it should be remembered that the best results are obtained only from apparatus which can be thoroughly comprehended by the operator in charge. If the installation is such that only the most economical and simple control is warranted, that shown in Fig. 1 is designed to meet this service. In the majority of cases the conditions are such that it is desirable to obtain results beyond the possibilities of this simple manual control, and for these reasons, magnet switches have been designed. To secure refinement of their operation, this type of control becomes complicated to such an extent that the ordinary operator is not able to keep it in good working condition. The simplicity of the liquid regulator insures better service, as the operator can soon become familiar with it in detail and, from tests which have been made, it has been clearly demonstrated that no other type of control can approach its performance which, no doubt, explains its popularity in European practice where electric drive in the steel mill industry has received more attention and greater development than in this country.

The Design and Application of Rheostats

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BECAUSE THE FUNDAMENTAL PRINCIPLES of rheostat design and operation are so simple and so easily understood, the average engineer pays little attention to the subject. He seldom has more than a superficial knowledge of the limitations of various designs or the advantages and disadvantages of different types for any particular installation. The impression is also prevalent that a rheostat is a "hit and miss" device, consisting principally of "ohms," and that no particular care is used or is necessary in its design or application. In this article an endeavor will be made to correct this impression by outlining some of the general features of the design of different types of rheostats, indicating at the same time some of their limitations and advantages.

H. C. NAGEL

SO FAR as design is concerned, rheostats can be divided into two general classes,—those used for regulating duty which are in use continuously, and those for starting duty which are in operation only for short or infrequent periods. In the first case, the heat produced must be radiated at the rate it is generated; radiation is, therefore, the important factor. Starting rheostats handle heavy loads for short periods only. Thermal capacity is, therefore, the important factor in their design. The energy consumed in a rheostat reappears as heat, and a knowledge of the properties of heat is essential to the designer. In fact, a rheostat must be figured as a heater, designated to radiate or absorb a maximum amount of heat with a minimum of material before it can be considered most efficient.

Rheostats are commonly connected in series with the apparatus to be controlled and effect their control by varying the voltage supplied to the apparatus. This is accomplished by changing the resistance and the voltage drop across the rheostat and since, with each change of resistance, all the conditions of the circuit are changed, it is necessary to consider a rheostat design step by step.

Rheostats for continuous duty, such as field rheostats, motor speed regulators, battery charging rheostats, theatre dimmers, etc., are much the easier to design, because there are fewer factors involved, and these can be determined quickly and definitely. Field rheostats, such as shown in Fig. 1, are placed in series with the shunt fields of generators, direct-current adjustable-speed motors, rotary converters and synchronous condensers, for the purpose of controlling the voltage, speed or power-factor of the machine with

which they are used. Having given the limits over which control is desired, the maximum and minimum current required, the resistance of the field, and the supply voltage can be determined directly from the curves of the machine. The application of Ohm's law then quickly determines the resistance of the rheostat

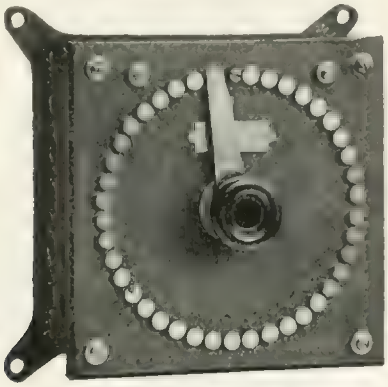

FIG. 1—FIELD RHEOSTAT—UNIT TYPE

required. For example, it is desired to adjust the speed of a 230 volt motor from 500 r.p.m. to 1 000 r.p.m. The motor curves show the field current at 500 r.p.m. to be two amperes and at 1 000 r.p.m. to be 0.5 ampere, while the shunt field resistance is 100 ohms, cold. With a line voltage of 230, the total resistance in circuit to give 0.5 amperes must be 230 divided by 0.5 or 460 ohms. Subtracting from this the 100 ohms in the field gives 360 ohms for the rheostat. If the number of steps, or the speed change per step, is given, the motor speed curve can be properly divided and each step figured out in the same manner. This, of course, would be a tedious process, and it is, therefore, customary to assume that the resistance steps will be equal or will vary at some uniform rate, usually an arithmetical or a geometrical progression. The rheostat engineer can then lay out curves covering the general case, and refer his subsequent designs to them to avoid repetition of work.

The number of steps to be used is largely a matter of standard practice, which dictates that a certain percent regulation is necessary and should not be exceeded. The engineer must watch his design to see that the voltage drop between steps is kept below certain safe values, determined by test, above which an arc will be maintained, and thus cause flashing and burning of the rheostat contacts; and if necessary to avoid this trouble, he must increase the number of steps beyond that demanded by the degree of regulation. When the number of steps, and the resistance and current of each is once determined, the watts loss is easily determined from the formula, $W=I^2R$, and the engineer is ready to lay out the resistor. The example shown above assumed a constant voltage and a fixed resistance in series with the rheostat. This condition is true of all field rheostats for motors or for separately excited machines, but it is not true for all cases. With self-excited generators, the voltage varies, but since exact figuring shows very little differences in total losses, it is customary to assume that the voltage is constant at the normal rating. With battery charging rheostats and motor speed regulators, the line voltage is constant but the counter e.m.f. of the battery or motor (which corresponds to a resistance) is a varying quantity, and the resistance of the rheostat must be figured step by step.

Regulators for adjusting motor speed by series resistance probably offer the greatest difficulties of any of the continuous duty rheostats, and are more liable to cause dissatisfaction. The amount of resistance required is a direct function of the armature current which varies as the load on the motor. In figuring on a speed regulator, therefore, the designer must assume values for armature currents at various speeds, and if the actual facts do not agree with his assumptions, he is blamed for poor design. Customers in ordering regulators may fail to give the motor application correctly or to state the actual load on the motor. If, for example, a regulator is desired that will give 50 percent speed reduction on a ten horse-power motor operating on such service that the torque will be constant regardless of load, the designer should be pardoned if, after making a rheostat suitable for a ten horse-power load, the customer discovers that the actual load is only five horse-power and he can get only 25 percent speed reduction with the regulator supplied. In many cases the motor is applied where the torque is a function of the speed, and as it is often very difficult to secure correct data from which to work, the engineer is frequently called upon to make various assumptions. By some means, however, he is obliged to determine the resistance and ampere capacity for each step of the rheostat, and is then ready to lay out his resistance elements to agree. A great many

FIG. 2—PLATE TYPE FIELD RHEOSTAT

rheostats are built up of resistance units which have been thoroughly tested and rated for a given wattage. Rheostat design is then simply a mechanical grouping of the requisite units to care for the resistance and capacity determined upon.

A large number of so-called plate rheostats are

used for small capacity work. These consist essentially of a round plate, either of insulating material or of iron with a layer of insulation on which the contacts and resistance material are mounted. This resistance material is disposed in flat loops lying against

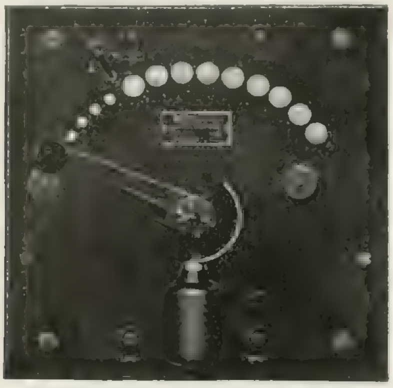

FIG. 3—SPEED REGULATOR FACE PLATE

the plate and is then covered with insulation of some character, usually a cement or enamel. The whole plate is given a definite watt rating and the size of plate to use for a given set of specifications is figured by getting the summation watts of all the steps. Where the size of the plate would prove unwieldy, two or more plates are connected in parallel. The construction of these plates is such that practically no repair work is possible and a burn-out or a ground means an entirely new rheostat. With a rheostat of the unit type, where individual units are assembled to make up a complete rheostat, any damage is usually confined to one or two units which can easily be replaced. There are many different forms of units in use, but a general type for all small and medium capacities consists of an insulated support, wound spirally with resistance wire and provided with suitable terminals. Some of these are encased for the double purpose of protecting the wire and providing additional thermal capacity to care for overloads; some are protected with a thin coating of enamel or cement; and some have no protection at all. With any of these units, the assembly is so arranged that the maximum surface is exposed for radiation and the design is made such that the heat generated can be carried off most expeditiously.

In any type of wire-wound resistance units, the limit of capacity is reached at comparatively low ampere ratings. The mechanical difficulties of winding units of heavy wire, or of connecting units in multiple to secure large ampere capacity, prove prohibitive above a certain point and some other type of unit must be used. Cast grid resistors are almost universally used for large capacities, but since the foundry cannot cast grids with sufficiently small sections to give high resistances, grids cannot be used economically for small capacities. In so far as costs are concerned, it is economical to use grids for capacities which represent the high limits of wire-wound resistors, but such designs do not show economy in space or weight. Because the cast grid is such a good resistor, many attempts have been made to produce a design giving higher resistance units with the same general characteristics. One scheme involves the punching of grids from sheet metal. It is found, however, that high resistance materials are expensive, and that with cheaper materials, in order to secure high resistance, the section of the grid has to be so small as to be weak and flimsy. Such grids are subject to rapid deterioration from oxidation and have not found favor to any extent. Another design shows a woven wire mesh grid, the warp of which is the resistance element insulated from the woof. These grids have the advantage of very light weight and excellent radiation. The design allows considerable latitude in wire sizes and units can be produced with a wide range of resistance values. The mechanical difficulties of supporting the grids properly and bringing out the necessary terminals, combined with a rather high cost, tend to limit the use of this unit to certain classes of work.

Moulded or cast units, made of some form of carbon or silicon are used to some extent, although it is a very difficult matter to make them of predetermined resistance or to secure satisfactory terminal connections. Such resistors are apt to be unstable, changing their resistance after being heated, and as the temperature coefficients are usually high, their use is also limited.

Rheostats of the carbon type are usually made up from unit plates or discs of the resistance material,

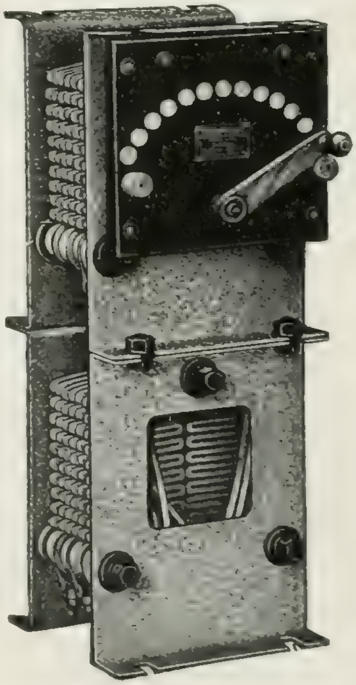

FIG. 4—BATTERY CHARGING RHEOSTAT

but instead of varying the resistance of the whole rheostat by switching the units in or out of circuit, as with those already described, the operating mechanism increases or decreases the pressure between units and varies the total resistance through the inherent prop-

erty of the material to change its resistance with change in pressure. Resistors of this type are unstable because it is practically impossible to regulate the pressure with any degree of exactness, and because the material has a high negative temperature coeffi-

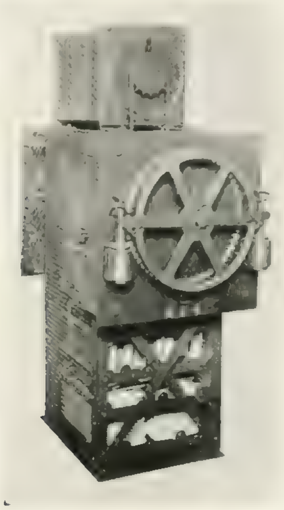

FIG. 5—SPECIAL BOOSTER FIELD RHEOSTAT

cient. A given pressure will produce a certain resistance and allow a certain current to flow. This current produces heat which increases the temperature and lowers the resistance to admit more current, etc., while at the same time the expansion due to the heat may add to the pressure and still further reduce the resistance. This type of resistor has the advantage that all of the resistance material is working all the time at a uniform rate whereas in the unit type only a part of the resistance is working at a maximum at any given moment, and some portion may be out of circuit altogether. Theoretically therefore, the carbon type rheostats should be smaller for a given rating, but, owing to the better ventilation possible with the unit type construction, this is not borne out in practice. There are a great many different types of units and resistors, but most of them can be classified as modifications of the general forms mentioned above.

The face plates or switching apparatus by which the resistance is controlled are worthy of a brief study. Nearly all designs have the contact points arranged in the arc of a circle, at the center of which is pivoted a movable contact arm, arranged to cut the resistance in or out of circuit, step by step, although some designs are made with the contacts in a straight line, the movable contact being attached to a nut traveling on a screw thread. Most face plates are arranged for manual operation, either directly or through sprockets or gearing, but for applications where such control is not advisable, electrically-operated face plates which can be operated by a distant control switch are obtainable. The operating mechanism may be actuated by solenoids or a motor, and with such control it is feasible to secure automatic regulation.

For booster fields, where it is necessary to reverse the current flow without opening the circuit, rheostats can be made with two face plates [illegible] to operate simultaneously. The arms are insulated from each other and each is connected to one side of the field to be controlled. One resistor only is used and this is placed across the line, with connections to both face plates. With the rheostat arms in the extreme position, the field receives the maximum current and movement of the arms reduces this by steps to zero at the point where the arms are both at the middle point of the resistor. Further movement increases the current to a maximum again with a reversal of direction.

Motor speed regulators are usually provided with automatic no-voltage release and often with overload protection, in the same manner as starting rheostats.

Battery charging rheostats are similar in design to field rheostats, but the number of steps required is considerably less and the controlling mechanism therefore can be made more cheaply. A large number of charging outfits are sold to garages and to automobile owners, where the persons in charge have little, if any, knowledge of electricity or the theory of battery charging. The rheostat must therefore be liberally and ruggedly designed to withstand operation by unskilled labor.

Special rheostats for all sorts of regulating work are being made continuously, but they offer no difficulties to the designer if he can secure the necessary data in regard to the application. In most cases the rheostat can be assembled from standard stock parts or standard forms of construction slightly modified.

It has already been said that rheostats for starting duty offer different problems of design. When beginning the design of a rheostat to start a motor, the designer has but two fixed values—the nominal horse-power rating and voltage of the motor to be started. If he is designing for a particular case, information is sometimes available as to the actual starting conditions, but in the general case, the designer must make assumptions in regard to the length of time taken to start the motor, frequency of the starting operation, current required at different points on the rheostat and the allowable temperature rise of

FIG. [illegible]—STARTING RHEOSTAT WITH OVERLOAD RELAY

the resistance. For these, he must rely upon experience and standard practice. He knows that motors of small or medium size can readily be started in fifteen seconds or less, and that the length of time required to start increases with the size of the motor.

In some installations, the starting is infrequent, while in others, the starting rheostat is used often. The American Institute of Electrical Engineers (in its old standardization rules) recommended that a starting rheostat should be designed so that the motor could

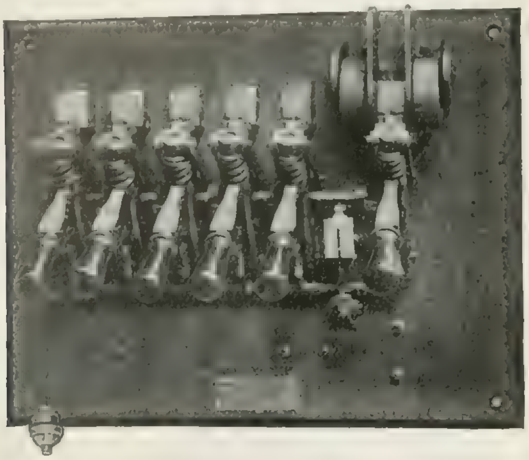

FIG. 7—MULTI-SPEED PANEL TYPE OF STARTER

be started once every four minutes under 50 percent overload during one hour, with fifteen seconds allowed for each start. This covers more severe starting conditions than would be found in a general case, and a rheostat designed to meet these specifications will usually be found satisfactory.

It is common practice to limit the initial rush of current admitted to the motor to full-load value, and this then determines the total resistance of the rheostat. Having determined the total resistance, the current, the time required for starting and the frequency of starts, the designer is prepared to go further into details and desires to know the number of steps required and the proportion of the resistance in each step. He usually has available a suitable switch or face plate which gives the total number of steps, and he is most concerned with the proper distribution of the resistance. A curve can be plotted showing the relation between the steps and resistance, which is most convenient for determining this. This curve can be figured by assuming certain rushes or peak values of current which should not be exceeded when a resistance step is cut out, but as these assumptions must be based on experimental test, it is preferable to make the curve the composite record of a large number of tests which gives smooth acceleration of the motor. Figuring the resistance per step on this curve completes all the preliminary estimating and the designer is ready to lay out the resistor.

FIG. 8—COMBINED STARTING AND FIELD RHEOSTAT

In a starting rheostat, large quantities of heat are generated during the short period of starting, as the energy in the rheostat at that time is equivalent to the full and often the overload rating of the motor. Since in the short period of starting, there is time for very little heat to be radiated, a greater portion of the heat generated must be absorbed in the rheostat and it would, therefore, seem that the ideal rheostat would consist of a large mass of cheap material having high thermal capacity. In support of this conception, there are rheostats in which the resistance elements of wire or strap are embedded in some form of cheap heat conducting material, such as sand or cement. If properly designed, such a rheostat can be made satisfactorily for small capacities or for infrequent starting. The design is not suitable for frequent starting, beause in making a number of starts close together, there is an accumulative effect which tends to raise the temperature to dangerous limits; nor is it suitable for large capacities, due to the inherently poor radiating qualities of this type of resistor. All of the heat generated must be ultimately dissipated by radiation into the air, and since, with a solid mass of material, the total radiation depends on the surface area exposed to the air, while the thermal capacity is directly proportional to the cubic contents, it can readily be seen that the ratio of absorption to radiation will increase with size. As the ratio is always greater than unity, except for very small capacities, the time allowance for dissipating the energy received must steadily increase with size and soon become so great that the design has no practical value.

FIG. 9—MOTOR-OPERATED FIELD RHEOSTAT FACE-PLATES

In laying out a starting rheostat and in determining the size required, etc., it is helpful to calculate the total heat over a cycle of operation. If a rheostat has been laid out in accordance with the above explanation and it is assumed to operate according to the A. I. E. E. test specifications, or some other definite cycle, the heat generated during a given period may be determined. If it is further assumed that the radiation is practically constant during the whole time, the rate of radiation required to take care of all the heat generated can then be determined, and the size of the resistor necessary can be determined approximately from a knowledge of continuous capacity rheostats.

A large number of the starting rheostats on the

market today are of the unit type. The units are of the same general design as those previously described, although the tendency is towards the use of those which have large thermal capacity as well as good radiation. Cast grids are particularly well adapted for this service and are used as far as possible. As mentioned above, however, it is not practical to use cast grids for small capacities and therefore wire wound units are used for rheostats of small size, or some other form of resistor. It is not so essential that accuracy of resistance be maintained and the carbon type resistor reaches its highest efficiency in this service. Cheaper resistance materials which, on account of temperature coefficients, etc., would not be suitable for field rheostats, can often be used here, and some manufacturers claim a decided advantage in the use of iron wire, because this has such a high temperature coefficient that a rheostat made of it will, if accidentally left on the circuit, protect itself automatically, due to its increased resistance.

The general design of the operating mechanism on practically all rheostats of small and medium size is the same—the difference between different types being in the minor details or in the operation of protective devices. A low-voltage release is almost always included. This returns the operating lever to the starting position and opens the circuit whenever the supply voltage falls below a predetermined amount. This device consists of an electro-magnet which retains the lever against the operation of the returning spring and practically the only difference between different designs is in the connection of the coil. Some rheostats have the coil in series with the shunt field of the motor. This is really the best place for it because the device then protects the motor from failure of the supply of voltage or from open circuit in the field. With series motors, or with adjustable speed motors where the field current varies over a wide range, the coil has to be connected across the line, and since this scheme of connection is independent of the design of the motor, whereas, in the other scheme the field current of the particular motor application had to be determined, it has become standard for nearly all cases. In order to limit the current shunted by the coil, a high resistance must be placed in series with it and this resistance is usually the weakest part of the entire design. On high voltages especially, the resistance is so high that very fine wire must be used and this is so weak mechanically that in case of rough treatment, it usually fails first.

Overload features of various kinds are often used. These vary from a simple relay opening the low-voltage release circuit, to a practical circuit breaker. A relay is inoperative during the starting period and is therefore of no value in limiting the starting current, but in some installations it is useful as a current indicator to save fuses because it can be set lower than the fuse rating and will open the circiut before the fuse will blow.

For motors of large capacity where the current is too heavy to be handled properly by a sliding contact, a series of switches or circuit breakers are mounted on a panel and interlocked so as to operate in sequence. Most starters have the resistors conconnected so that each switch cuts out a portion of the total resistance, the same as with the sliding contact, but some are arranged to throw the different resistance steps in parallel to decrease the total. This latter arrangement is seldom used except for very large capacities where it shows some economy.

It is, of course, bad practice to start up a motor with a weakened field and it is therefore natural that there should be schemes to prevent this. Some starting rheostats are provided with a relay connected with the field rheostat which makes it impossible to start the motor unless the field rheostat is all cut out. Other designs combine in one mechanism the functions of starting and regulating, so that they must be performed in their regular order. Starting rheostats are usually mounted close to their motors, or at least in sight of them, and, with rare exceptions, are arranged for manual operation. There are many automatic starters on the market which, under certain conditions, will accelerate a motor properly, but these are usually supplied as a component part of a control system. The fundamental design is unchanged but electro-magnets perform the same work as the operator of the manually-operated device.

All commercial rheostats are built of non-combustible materials and are practically fireproof. Many of the resistors could be run red hot for an indefinite period without injury, but such a high temperature would constitute a serious fire hazard and could not be countenanced. Many designs are limited by construction or by the properties of the materials used to certain maximum temperatures and in order to avoid trouble these would have to be rated so that under the worst conditions of overload there would still be a margin of safety between the operating temperature and the maximum. With modern materials, however, the temperature limit obtained in this manner would still be objectionable to operators and the actual ratings used are based on external conditions rather than on the design itself. A temperature rise exceeding 100 degrees C. on the outside casing of the rheostat is looked upon with suspicion and this temperature is close to the maximum found on any standard designs. The temperature rise of the resistance element will be much higher than this and will vary according to the type of designs, but the writer believes that but few examples will be found among commercial rheostats where this temperature will exceed 300 degrees C. and in most cases it is considerably lower. These figures can, therefore, be taken as maximum for conditions existing today. It is quite probable that, as the public comes to realize that higher temperatures mean greater efficiency and lower cost, rheostats will be mounted so that these values can safely be exceeded.

The Selection of Control for Portable Drilling Rigs.

W. R. JOHNSTON

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ORIGINALLY there was some question as to the suitability of any type of motor for drilling work. Some of the more adventuresome operators decided that the distinct advantages of electric transmission of power and the elimination of fuel and water, warranted a fair trial. They were inclined to believe that there was little risk involved, in that motors had already proven successful in hauling heavy trains, in steel mill service and in other severe work. The application which attracted the earliest attention was the small portable rig used in drilling blast holes to a depth of 50 to 150 feet in quarries and mines. Here electric power was available from the operators' generating plants or from the central power companies' lines. With the current at hand it was soon demonstrated that either direct or alternating-current motors could be used to equal advantage, and not until deeper drillings were attempted was it found that the selection of the proper control determined the degree of success of the installation. Operations to be performed in any depth of hole are now so thoroughly understood, however, that proper control can be furnished in every case, and manufacturers of drilling rigs have no hesitation in calling for electrical equipment. It should be noted that the following discussion is based primarily on conditions as met with in connection with the portable type of rig shown in the accompanying illustrations. Undoubtedly there will be cases such as arise in California where different conditions demand different types of control, but it is felt that the discussion given herewith will facilitate the selection of control for any work a portable drilling rig may be called upon to do.

IN DRILLING with portable drilling rigs a tool weighing between 500 and 2 000 pounds is suspended at the end of a hemp or steel cable and alternately raised and dropped in such a manner as to impinge upon the rock surface. The force with which it strikes depends upon the unrestrained fall, and the selection of a proper drilling speed. The dependence of this force on the first of these features is readily seen when it is considered that it is the impact, as represented by 0.5 MV², that crumbles and powders the rock, and that velocity is the bigger factor. Since the cable has no rigidity and cannot force the tool downward the velocity imparted to the tool is dependent entirely upon the acceleration due to gravity. To secure the greatest effect from this acceleration, then, it is very necessary that there be nothing to hold back on the tool and that it have a free fall. This is obtained electrically by the use of a motor having poor speed regulation; that is, a motor that will slow down in picking up the tool and speed up sufficiently when the tool descends to prevent the latter from over-hauling the motor. Such a motor may be either of the alternating-current type operated with resistance in its secondary circuit, or of the direct-current type having series characteristics with just enough shunt field to prevent the motor from running away at no load. Furthermore, the force of the blow in dropping is augmented by selecting a drilling speed in synchronism with the periodicity of the cable. In such a case the tool is hurled upward a greater distance and has a correspondingly greater free fall with a greater breaking blow. To obtain the

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proper drilling speed requires feeling out the motion of the tool and this means a close speed adjustment.

It will be appreciated that, as drilling progresses and the cable is paid out. the periodicity of vibration will change with the increasing length and demand small changes in speed from time to time, and owing to the slow progress made in drilling, it becomes evident that a control and resistance must be selected which will maintain these different speeds.

The close adjustment and range of speed are obtained in a direct-current motor by the use of field control, as shown in Figs. 1 and 2. In the case of the alternating-current motor, a drum controller operates resistors designed to give a 50 percent speed reduction in the manner shown in Figs. 4 and 5. In either case the control and resistance are selected for variable-speed continuous service.

While practice has shown that field control of a direct-current motor affords the flexibility of speed required by the deepest wells handled by portable rigs, it also has shown that the standard alternating-current controller alone does not afford a sufficiently close adjustment at depths of 1 000 feet and greater. For this reason it sometimes becomes necessary to supplement the main drum controller with an auxiliary drum controller, as indicated in Fig. 5. It will readily be seen that in such a system the main controller cuts out the large resistance in twelve steps and the auxiliary controller, working independently, shunts out its resistance in six steps equivalent to each step in the main resistance. In this way 72 points of control are obtained. Usually a nine and six point controller giving a total of 54 steps affords ample speed adjustment for the greatest depths handled by a portable rig. In the case of small rigs, as shown in Fig. 6, a nine point controller amply meets the requirements.

BAILING

Bailing is necessary in any depth of hole in that

if the broken rock were allowed to remain it would materially impair the efficiency of drilling. To avoid this the tools are brought to the surface and a long iron pipe with a flap valve at its bottom lowered. On striking, the valve is pushed up and a mixture of mud and water flows in. It may be necessary to raise

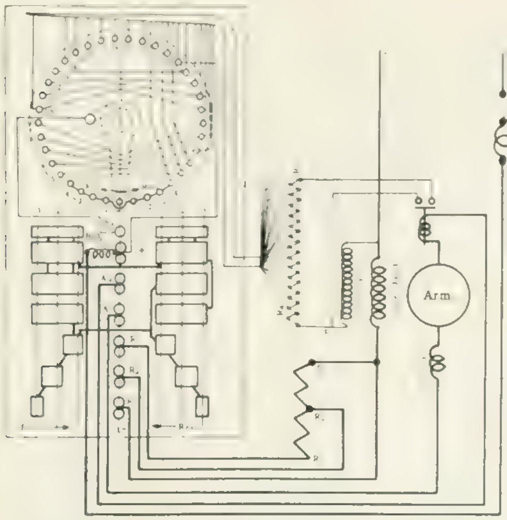


FIG. 1—DIAGRAM OF DRUM CONTROLLER WITH FACE-PLATE FIELD RHEOSTAT AND FLUTTERING RELAY

and lower the bailer several times through a height of six to ten feet in order to get a good load, after which it is raised to the surface and emptied. The tools are then run back and drilling resumed.

With a given weight of cable and tool for a given formation, drilling is limited to one best speed for each depth and there is consequently no opportunity for increasing the rate of drilling by raising the speed of the motor. In bailing, however, there is an opportunity for saving time and usually the maximum speed consistent with safety is selected for hauling the tools from the hole, and raising and lowering the bailer.

Due to the method of operating it is necessary to select some system of control which will permit of ac-

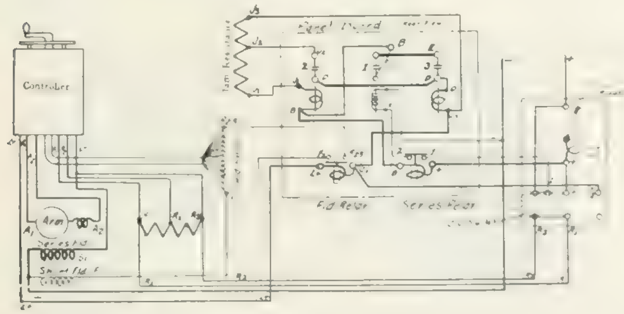


FIG. 2—DIAGRAM OF THE CONTROLLER SHOWN IN FIG. 1, WITH THE ADDITION OF A JAM RESISTANCE AND AUTOMATIC MAGNET SWITCHES FOR THE HEAVY CURRENTS

celerating the motor to full speed in the quickest possible time consistent with motor design, but no faster. With a direct-current motor this is accomplished automatically by the use of a fluttering relay, as shown in Fig. 1, which limits the current taken in accelerating to a certain predetermined safe value. This will be explained in greater detail later. With an alternating-current motor, because of the very intermittent character of the work, it is permissible to set the circuit breaker at a current value just below that corresponding to the pull-out point, and this enables the operator to accelerate his load more rapidly than the design of his portable rig will stand. Hence, the driving motor is in no danger of being started up at a dangerous rate.

JARRING DOWN CASING

In addition to the general conditions described above there is a further difficulty to be met, particularly in deeper drillings from 500 to 1 500 feet in that quite frequently loose earth, quick-sand, and water-bearing strata may be encountered. Under such circumstances it is necessary to locate a long column of pipe below the point of trouble and pass the tool through this pipe to drill ahead of it. An additional string of pipe is placed within the outer one for each occurrence of trouble.

In placing this pipe or casing quite often it will not go down easily because the hole is not drilled straight or there is a shoulder of rock the tool has avoided. Under such conditions the entire length of pipe is raised and allowed to sink back by its own weight until it has worn past the obstruction. This is known as jarring down the casing. In raising the total length of pipe against the friction of the sides, say five or six times, a considerable duty is imposed on the motor and control. With alternating-current motors, the increased requirements for this service can usually be met with a motor with a pull-out torque of approximately two to three times full-load torque. In the deeper wells, demanding a double drum control, this torque may not be sufficient and a star-delta switch is mounted on the motor which permits of the development on delta of approximately six to eight times the full-load torque obtainable when operating star connected.

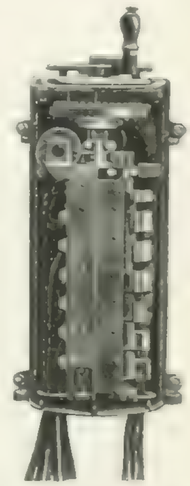


FIG. 3—TYPE [illegible] CONTROLLER SHOWN DIAGRAMMATICALLY IN FIGS. 1 AND 2

Occasions may arise (particularly where only low voltage such as 220 volts or less is available) where the current corresponding to this pull-out torque could not be handled directly with a drum controller without excessive burning, and to keep this to a minimum, two two-pole magnetically operated switches are used for closing, opening and reversing the primary circuit of the motor. These switches are made operative by the primary contact drum of the main controller and the only currents handled by this drum are the small currents required to energize the coils of the switches.

OPERATION OF CONTROLLER AND AUXILIARY

The operation of these switches may be seen by reference to Fig. 5. It will be noted that a movement of controller *I* to the right closes contacts L_1 and *2*, thus completing the circuit L_1 through coil 2-L_2 of the magnet switch and causing the switch to close. The main power circuit is immediately established through L_1 to motor terminal *C*, and L_2 to motor terminal *B*. Line L_3 runs directly to the motor so that this terminal is always alive whenever the circuit breaker is closed. Continued movement of the controller handle to the right shunts out the main resistance step by step. If it is found in drilling that the proper speed lies between, say point *4* and *5*, the operator then operates controller *II* to cut out his auxiliary resistance, until the desired speed is attained. If it is desired to reverse the motor the main controller *I* is brought back to the off position and movement continued to the left. It will be seen that the circuit of coil L_2-1 is closed at points 1-L_1 and the

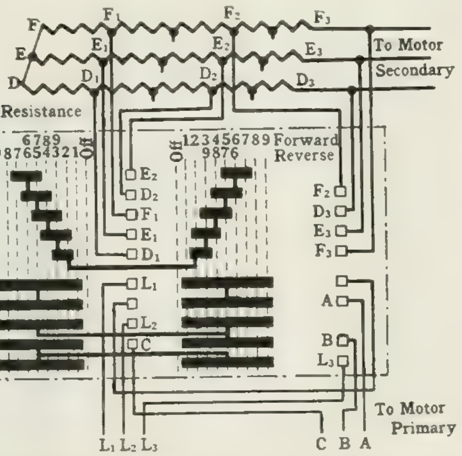


FIG. 4—CONNECTION DIAGRAM OF A DRUM CONTROLLER FOR A WOUND-SECONDARY POLYPHASE MOTOR

lower switch closed. The upper switch drops out when the handle is brought back to the "off" position. Closing the lower switch establishes the main power circuit lines L_1 and L_2 to motor terminals *B* and *C* respectively and, the current of one phase having been reversed, the motor starts up in the opposite direction. Continued movement to the left cuts out the main resistance step by step, and if the desired speed in the reverse direction is not obtainable on the main controller, recourse may be had to the auxiliary control. While these two drums are electrically connected there is no mechanical connection, and where rapid acceleration is required, as in bailing, the auxiliary controller is not used, so that the operator has only the friction of the single main drum to overcome.

The reversing feature of the controller is not needed for any of the main operations of drilling, as the reciprocating motion in drilling is obtained by driving a crank, and the reverse motion of the drums in bailing and handling casing is secured by unclutching the hoisting drum and lowering the casing or bailer by gravity. The principal need of reversing the motor is when the drilling, bailing and casing cables are to be unwound from the drums in changing from one operation to another.

In protecting the motor against the high currents that may be required in handling casing, a circuit

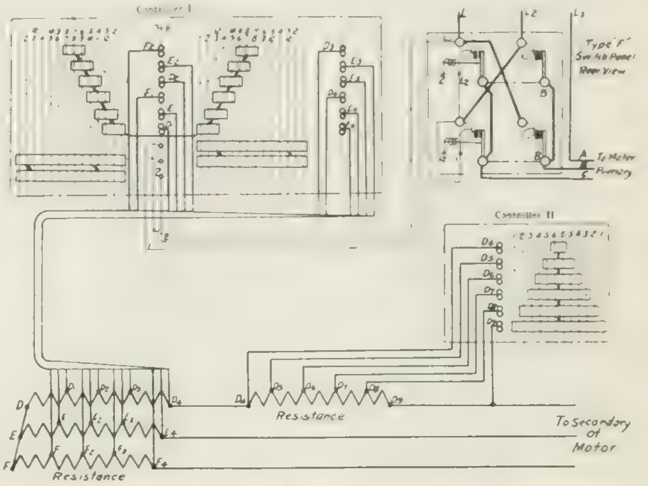


FIG. 5—CONNECTIONS FOR A MAIN AND AUXILIARY CONTROLLER TO GIVE 72 STEPS

breaker with a dash-pot time-limit device is furnished so that it will not trip out on peaks and yet will provide adequate protection against lower continuous overloads. No-voltage protection is so arranged that in case of failure of power the operator will have to reset the circuit breaker before operations can be resumed.

The present type of circuit breaker does not have a sufficient range of current setting to give accurate protection on both star and delta operation, and it is usual practice to add fuses to give protection on the star connection. This is done by means of a three-pole single-throw switch so arranged that when it is desired to operate the motor on the delta connection,

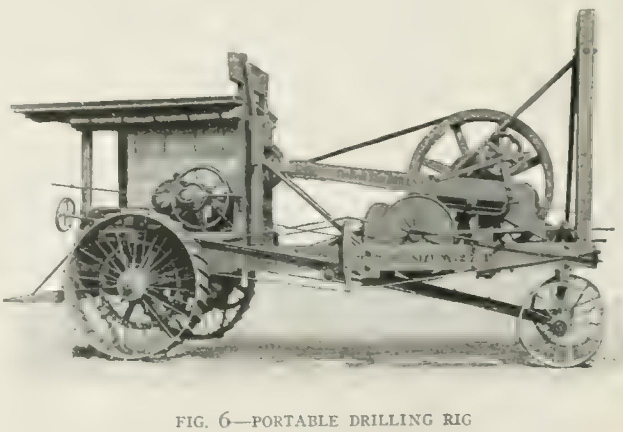


FIG. 6—PORTABLE DRILLING RIG
Manufactured by the Loomis Machine Company.

closing the switch will shunt the current around the fuses, while opening the switch will send the current through both the circuit breaker (with its delta current setting), and the fuses.

While the delta connection is available for handling casing with an alternating-current motor, some

other expedient must be resorted to in the case of the direct-current motor. Of course, a direct-current motor of series characteristics would tend to develop a large torque, but this is limited in commercial design to the safe commutating and heat dissipating

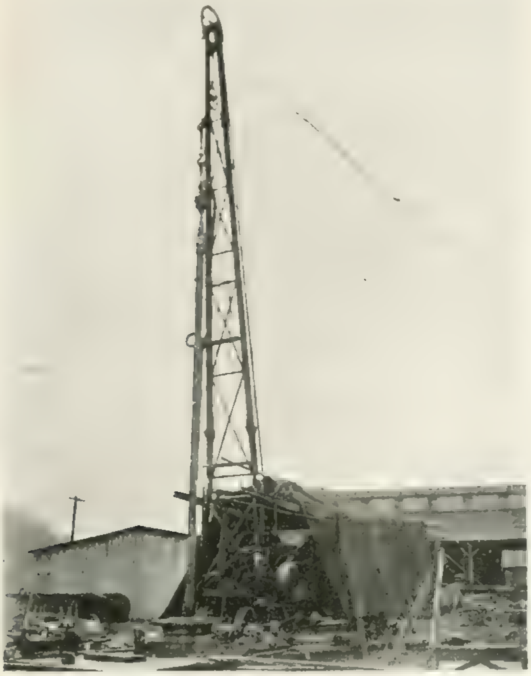


FIG. 7—MOTOR-DRIVEN PORTABLE DRILLING RIG
Manufactured by the Oil Well Supply Co., Pittsburgh.

ability of the motor. The torque sufficient to pull out the casing would require a motor having six times the torque necessary for regular drilling with the additional disadvantages of increased cost, unstable operation on light work and poor efficiency about 95 percent of the time. This has been avoided by the selection of a control which permits a compound-wound motor to develop two to 2.5 times full-load torque for one-half to two minutes at or nearly at a standstill. The saving in capacity made by this feature will be seen when it is considered that a jerk of considerable magnitude might fail to overcome the inertia and static friction of, say 1 000 feet of iron pipe, while a slow, steady pull of less magnitude would be effective. The manner in which this is accomplished is by means of two relays which operate when the current reaches a predetermined value. One of these relays places full field on the motor regardless of the position of the control handle and the other places a jam resistance in series with the armature, designed to permit a predetermined value of current to flow with constant line voltage and the motor at standstill. With full field and a known value of armature current the motor automatically develops only a known safe torque regardless of the extent of the overload.

This type of control has demonstrated its worth on portable rigs of the type shown in Figs. 7 and 8 capable of drilling efficiently to depths of 1 500 feet. This rig is a tractor which carries its own power plant and moves itself from hole to hole. The power plant consists of a high-speed automobile-type engine driving a generator which furnishes power to an adjustable speed field-controlled direct-current motor. This motor drives the rig, does standard cable or rotary drilling and has shown its ability to meet every operation incident to sinking and properly casing a hole.

The particular arrangement of control which has demonstrated the ability of a direct-current motor to handle this work, where without this control, it had failed, is shown in Fig. 2, the operation being as follows:—In starting the motor to drill, the operator moves the handle up to a position where experience has told him he will find the approximate drilling speed for that depth. In so doing he passes over the first three points which insert resistors R_1R_3 and then cut them out in two steps. If this operation is performed too rapidly the motor will be protected by the automatic insertion of the jam resistance J_1J_3 or the operation of the circuit breaker, depending upon the position of the two-pole double-throw switch. Continued movement of the handle cuts in the field resistance until the desired running speed is reached and drilling started.

Consider now that a careless operator had turned the handle directly to a weakened field point. This sudden weakening of the field would cause a rapid falling off of the back e.m.f. generated in the armature and a corresponding reduction in the resistance of the armature circuit. The resultant increased current would operate the coil J_3L^+ of the field relay.

FIG. 8—GAS-ENGINE-DRIVEN POWER PLANT ON A PORTABLE DRILLER

The relay, energized, would place a shunt about the field resistance and immediately full field would be placed on the motor. The consequent sudden building up of the back e.m.f. would cause the current to drop again and so remove the shunt from the field resistance, thus immediately establishing a weakened field. This cycle would continue, alternately placing full and weakened field on the motor until it had accelerated to the speed corresponding to the position of the control handle. The rate of acceleration is determined by setting the relay to the maximum con-

sistent with the motor design and yet below the circuit breaker setting and the overload setting of the series relay.

It will readily be seen that this automatic acceleration will take place in drilling, bailing and handling casing. Of course, if the load placed on the motor is too great to permit of accelerating to full speed, the fluttering relay will be held down and so will establish full field. If this does not result in sufficient torque to accelerate the load the current will rise until the circuit breaker trips. This presupposes that the double-throw knife switch is closed to the right, Fig. 2. If it is found that on again closing the circuit breaker the motor is allowed to accelerate in taking up the slack, but the circuit breaker trips out the instant the motor has to pull hard, and all advantage of having started the load is lost, then the two-pole double-throw knife switch should be thrown to the left. This shunts out the circuit breaker and the accelerating resistance and also removes the shunt from the series relay and jam resistance. For the sake of convenience the usual case will be assumed; that is, where there is sufficient slack to permit the motor to accelerate to full speed before the load takes hold. Under these conditions, starting the motor by passing directly to full speed or any weakened field point would give rise to the following sequence of operation:—

In starting with accelerating resistance R_1R_3 short-circuited, there would be a rush of current sufficiently large to lock out the series switch *2* and yet not be high enough to operate the series relay. The locking out of *2* would prevent any current flowing through the series coil of switch *3* and so switch *3* would also remain open. With switches *2* and *3* open the accelerating current would be forced to flow through the jam resistance. As the current through the jam resistance and series coil of switch *2* falls below the lockout point of the switch it would close, thus shunting out a half of the jam resistance.

With current now flowing by the path indicated as BJ_1, J_1J_2, J_2D, DJ_3 and J_3L^+, switch *3* would be locked out until the current had fallen to a value below that at which switch *2* had closed. At this point switch *3* would close, placing a complete shunt around the jam resistance. Establishing a shunt about the jam resistance prevents current from flowing through the series coil BJ_1 and switch *2* falls open. The fluttering relay would now act to accelerate the motor to a point where all the slack was taken up, at which time the field relay, having a lower current setting than the series relay, would operate first, placing full field on the motor. The torque developed with full field not being sufficient, the current would build up, finally reaching a value at which the series relay would operate. This would open the circuit of the shunt switch *1* at points *1* and *2*, causing it to open and remove the shunt from the jam resistance. Under this condition the motor could be designed to develop two to two and one-half times full-load torque for a period of one-half to three minutes. If the casing cannot be moved in a half minute's time it is a pretty sure indication that it will be necessary to add another line to the block and tackle.

If, after the insertion of the jam resistance the casing is worked loose and the load gradually falls off, the series relay will be first to operate, closing the shunt circuit of switch *1* at points *1* and *2*. Further falling off of the current below the lockout point of coil BJ_1 will permit switch *2* to close and so shunt out half of the jam resistance. Current will now flow through the series coil DJ_3 and when it has fallen still further to a point below its lockout setting, switch *3* will close, again placing a shunt about the jam resistance. All resistance being removed from the armature circuit, the fluttering relay will immediately accelerate the motor to a speed corresponding to the position of the control handle.

By having the field relay set at a lower value than the series relay it is possible to operate the fluttering relay independently of the series relay, but the series relay can never operate independently of the field relay. This means that automatic acceleration may be had independently of the series relay except where a sufficient load comes on to operate the jam resistance. At such a time full field is placed on the motor so that a maximum safe torque may be developed but nothing higher.

The adaptability of these features to all types of drilling service can be readily seen, and their adoption has permitted the successful use of the direct-current motor with its economically obtained wide range and close adjustment of speed by field control. On the other hand, the high momentary peaks afforded by a star-delta switch combined with adequate speed characteristics and low transmission losses makes the alternating-current motor particularly adaptable where operations are carried on at some distance from the power plant.

In conclusion it may be said that what appeared to be a serious motor problem has since been overcome by a more thorough knowledge of the requirements of the service and the selection of the proper control. This selection has permitted taking advantage of the inherent characteristics of the electric motor, namely high overload capacity, quick reversals of direction of rotation, its ability to develop the pull required the instant power is turned on and to develop an increasing pull as the speed drops off due to increasing load. Undoubtedly, when operators in general have seen the advantages and success of electric drive, there will be a rapidly increasing use of motors for this service.

THE JOURNAL QUESTION BOX

Our subscribers are invited to use this department as a means of securing authentic information on electrical and mechanical subjects. The topics should be of general interest; information involving the specific design of individual pieces of apparatus cannot be supplied. Care should be used to include all data necessary for an intelligent answer.

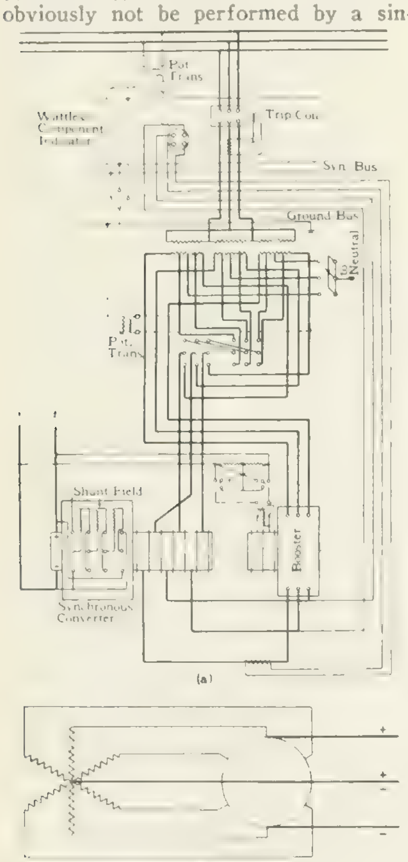
A personal reply is mailed to each questioner as soon as the necessary information can be secured, providing a self-addressed, stamped envelope accompanies the query. As each question is answered by an expert and checked by at least two others, a reasonable length of time should be allowed before expecting an answer.

1136—Converter Neutral—Why is it necessary to have the neutral from each transformer shown in Fig. 1136 (a) on a separate switch to the direct-current neutral? What amount of unbalance will this arrangement take care of properly? What would be the division of the unbalanced current through the transformers?

C. F. P. (ONTARIO.)

It is necessary to have this switch open when starting the converter from the alternating-current end, to prevent a partial short-circuit and enable the converter to start. This function can obviously not be performed by a single-pole switch in the common neutral. It may be closed as soon as the starting switch is thrown to the running position. Most rotary converters will then take care of full-load current between one line and neutral when the current in the other line is zero. The unbalanced direct-current will appear at the neutral in each transformer as an alternating current having a magnitude nearly one-half that of the unbalanced direct current.

J. L. Y.



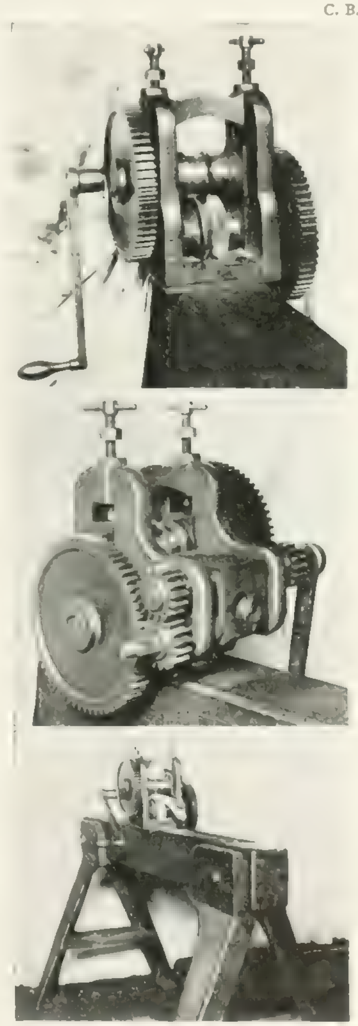
FIGS. 1136 (a) and (b)

1137—Removing Insulation—Will you please give some good method for removing asbestos insulation from scrap lengths of cable?

V. C. D. (TENN.)

The machine illustrated in Figs. 1137 (a), (b) and (c) is very effective for removing insulation. The circular cutting wheel or knife opens the cable covering longitudinally, being set by the screws so that it just touches the metal. After thus laying it open the cover as a rule falls off or is easily removed by hand. The cable is fed through a block and gripped between the V-grooved wheel and cutter, and pulled through by revolving the wheel by means of the handle and gears.

C. B. A.



FIGS. 1137 (a), (b) and (c)

1138—Testing Watthour Meter—A five ampere, 100 volt integrating wattmeter is guaranteed to be accurate within one percent on non-inductive load and at 80 percent power-factor. In testing this meter, should full-load current of five amperes be maintained in testing on both inductive and non-inductive loads? For instance on non-inductive load we would have 5 amperes × 100 volts = 500 watts, or 25 r.p.m. On loads having 80 percent power-factor we would have 5 amperes × 100 volts × 0.80 = 400 watts or 20 r.p.m., which is not full-load speed. Should the full load be rated according to full-load speeds of 25 r.p.m. or at rated full-load current of five amperes.

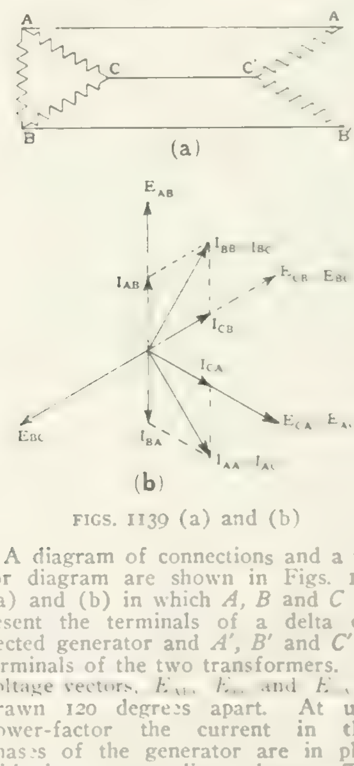
J. J. G. (N. J.)

Performance tests are made on the basis of current rating; that is, if full load is specified, full-load current is meant and not watts. For instance, a test at 50 percent power-factor and full load would mean full-load current, but only one-half load in watts. Hence, the disc should rotate at only one-half rated full-load, 100 percent power-factor speed.

W. M. B.

1139—V-Connection—Kindly show by vector diagram why the current lags 30 degrees behind the e.m.f. in an open-delta bank of transformers.

D. P. S. (IND.)



FIGS. 1139 (a) and (b)

A diagram of connections and a vector diagram are shown in Figs. 1139 (a) and (b) in which A, B and C represent the terminals of a delta connected generator and A', B' and C' the terminals of the two transformers. The voltage vectors, E_{AB}, E_{BC} and E_{CA} are drawn 120 degrees apart. At unity power-factor the current in these phases of the generator are in phase with the corresponding voltages. Then the current in the line AA' equals I_{CA} plus I_{BA}, added vectorially. But because the phase A' B' is open, the current in A' C' must be in phase with that in the line AA'. Hence, this current $I_{AA'}$ lags 30 degrees behind the voltage $E_{A'C'}$. Similarly the current in transformer B' C' leads the voltage $E_{B'C'}$ by 30 degrees. A similar diagram can be worked out for any other power-factor and it will always be found that with a lagging power-factor the angle of lag in A' C' will be 30 degrees more than that corresponding to the given power-factor and the angle of lag in transformer B' C' will always be 30 degrees less than that corresponding to the given power-factor. For example, at a power-factor of 86 percent lagging, the power-factor in A' C' will be 50 percent, and in B' C' it will be unity.

C. R. R.

Contributors to the Journal for 1914.

Contributors for whom biographical sketches have already appeared in December issues of previous years indicated by a (*)

*A. G. AHRENS, for the past six years has been directly associated with the application of electricity to steel mill service. This has involved a wide acquaintance with iron and steel engineers and the problems which they have to meet, particularly in the development of control apparatus.

*A. J. AIRSTON, head of factory lighting division, works management department, Electric Company.

J. H. ALBRECHT (Univ. of Mich., '10), one year on graduate student course of Electric Company, then entered the control division, engineering department on development and field work, remaining to date specializing on steel mill and machine tool control.

W. L. ALLEN, commercial engineer, R. D. Nuttall Company, Pittsburgh, Pa.

WILLIAM ARTHUR (Railway Institute, Horwich, England, and Univ. of Liverpool), apprenticeship course, Lancashire and Yorkshire Railroad and Locomotive Shops, England, 1893-1899; in steam locomotive designing and testing departments, and in electric traction department L. & Y. R. R. designing railway motors, control systems, rolling stock, third rail construction, etc., and working on experimental electrification work, 1899-1903. When the electrification of the Liverpool & Southport section of the L. & Y. Railroad (the first electrified steam line in England) was decided upon in 1903, was appointed assistant resident engineer superintending construction work; 1904-1907 operating this electrified system; 1907 railway department of the Electric Company at East Pittsburgh; 1908 electrical engineer of the Yale & Towne Company, Stamford, Conn.; 1909-1911, president and treasurer of the New Haven Wire Bound Box Company, New Haven, Conn.; 1912-1913, assistant engineer, electric traction department, New York, New Haven & Hartford Railroad; 1913, to date, general consulting engineering work with McHenry & Murray, Engineers, New Haven, Conn.

*C. B. AUEL, director of standards, processes and materials, Electric Company.

R. A. BALZARI (Univ. of Calif., '08) was employed by The Pacific Gas & Electric Company until Oct. 1st, 1908; with the Electric Company sales force in the San Francisco office to date.

E. C. BAUGHER (special course Univ. of Penn., '91-92; Johns Hopkins Univ., '93-94), superintendent of electrical construction, Baltimore & Ohio Railroad. 1895-1897. Entered testing department of the Electric Company, 1898; one year erecting apparatus in New York territory; in 1899 went to Japan as resident engineer of the Electric Company; later became commercial engineer in Japan, China and Korea; in 1907 returned to the United States as commercial engineer on rubber industries and general central station campaign in New England; now manager of railway and lighting division, Boston office, the Electric Company.

*H. L. BEACH left the Electric Company in 1909 to become electrical engineer of the Pennsylvania Coal & Coke Company; was promoted in 1910 to complete charge of the operation and maintenance of all plants, including power and lighting, repair shops and mining equipment; shortly after he returned to the Electric Company, specializing on the design of industrial control apparatus.

CHARLES M. BLACK, president, The American Electric Railway Association; vice-president and general manager, The United Railroads of San Francisco.

J. A. BLICKMAN (Univ. of Zurich, Switzerland, '04), after two years post-graduate work, entered graduate student course of the Electric Company, then manager of works department specializing on the introduction of high speed steel and its resulting changes in machine tools, and also the introduction of the premium system; after two years became general foreman of the small tool department; then accepted a position in Germany with the Maffei Works near Berlin, helping to erect a shop for the construction of electric locomotives and railway apparatus; followed by a position as superintendent of the Bergmann Electrical Works in the construction of turbines and large electrical machinery; then returned to the Electric Company at E. Pittsburgh as assistant superintendent of the department of switchboards and detail apparatus.

C. A. BODDIE (Univ. of Pitt., '08) entered the employ of the Electric Company in 1903 in the fuse and wire department, being transferred shortly to the draughting department: left the company in 1904 to enter the University of Pittsburgh, graduating in 1908; then with Jones & Laughlin on electrical repair work and subsequently general wiring work with the Pittsburgh Railways Company; returned to the Electric Company in 1909, spending one year as a graduate student; was transferred to the erecting department of the Boston office, remaining for a period of three years, when he returned to East Pittsburgh in the detail and supply engineering department specializing on meters.

H. F. BOE commenced work of an engineering nature with the Russell Engine Company of Massillon, Ohio, in 1899, remaining until 1901; then came to the Electric Company in the motor winding department, was transferred in succession to the inspection, testing, general engineering and industrial and power sales departments, in the latter two of which he has specialized on motors and control apparatus for printing presses, laundry, bakery and confectionery machinery, and fans and blowers.

*D. S. BOWMAN, commercial engineer, industrial and power sales department, Electric Company.

*O. A. BRACKETT, detail and supply engineering department, Electric Company.

*GRAHAM BRIGHT, general engineering department, Electric Company, in connection with the application of motors and control apparatus to industrial service.

W. G. BROOKS, railway and lighting sales department, Chicago district office, Electric Company.

DOUGLAS BURNETT, manager, commercial department, Consolidated Gas, Electric Light & Power Company, Baltimore, Md.

E. F. CARPENTER (Univ. of Minn., '11), graduate student course of the Electric Company for two years; then entered the detail and supply sales department, remaining to date, specializing on heating apparatus.

L. W. CHUBB (Ohio State Univ., '05), graduate student course, Electric Company one year; then a year in testing and standards department; entered the research engineering department in 1907, remaining to date. At present, engineer in charge of the electrical section on magnetic and electrotechnical research.

E. I. CHUTE (Univ. of Tenn., '04), for one year instructor in mechanical engineering in the Agricultural and Mechanical College of New Mexico; then came to Electric Company for two years as a graduate student; then entered the testing department where he has remained to date, having been promoted to the position of assistant superintendent of testing in April, 1913.

*C. S. COOK, manager, railway and lighting sales department, Electric Company.

L. P. CRECELIUS, superintendent of power, Cleveland Railway Company, Cleveland, O.

J. M. CURTIN (Penn. State, '98) took charge of the electrical equipment and operation of the Quinnimont Coal & Coke Company of W. Va. for a short time, followed by a two-year course as graduate student with the Electric Company; entered the sales department of the Electric Company; on alternating-current apparatus for two years; followed by a position in the office of Mr. F. H. Taylor, vice president at New York, remaining two years; in 1905 returned to East Pittsburgh in the industrial and power sales department, being made assistant to the manager in 1909, and in 1913 becoming manager of the department.

*W. M. DANN, transformer engineering department, Electric Company.

W. A. DARRAH (Worcester Polytechnic Inst., '10) entered U. S. Patent Office as patent examiner; later became a registered patent attorney; later with the Western Electric Company in the development division, finally becoming engineer in charge of lightning arresters and protective devices with this company; entered the employ of the Electric Company as engineer in charge of lighting apparatus in 1912, remaining to date.

A. R. DENNINGTON (Penn. State, '03-'05), assistant and instructor in electrical engineering at Pennsylvania State College, 1903 to 1907; assistant principal, electrical department, International Correspondence Schools, 1907-1911, including one year in London, England, with the International Correspondence Schools, Ltd.; with Westinghouse Lamp Company, 1911 to date, in charge of lamp development.

*G. C. DILL, detail and supply division, engineering department, Electric Company.

*E. P. DILLON, assistant to manager, railway and lighting sales department, Electric Company.

*C. R. DOOLEY, president, Casino Technical Night School; secretary educational committee, Electric Company.

*C. W. DRAKE, commercial engineer on motor applications, industrial and power sales department, Chicago district office, Electric Company.

*A. M. DUDLEY, industrial division, engineering department, Electric Company.

*S. W. DUDLEY, assistant chief engineer, Westinghouse Air Brake Company.

*H. B. DWIGHT, engineer on direct-current design, Canadian Westinghouse Company, Hamilton, Ont., Canada.

*G. M. EATON, engineer in charge, railway division, engineering department, Electric Company.

WM. C. L. EGLIN, second vice president, Philadelphia Electric Company, Philadelphia, Pa.

*R. S. FEICHT, manager of engineering, Electric Company.

H. W. FLASHMAN (Univ. of Sydney, N. S. W., Australia, Columbia Univ., '10), after experience in railway work, entered engineering apprenticeship the Electric Company in 1907; in 1909, with Mr. S. N. Clarkson; spent six months in a detailed study of European practice in power plant operation and construction and in railroad electrification; in 1911 was retained by the American Electric Railway Association to devise and inaugurate, under the direction of Professor H. H. Norris, a correspondence system of education for the younger employes of the electric railroads; now with New York office, Electric Company, specializing in railroad and power plant work.

*S. A. FLETCHER, industrial and power sales department, Electric Company.

WM. FOOT took a mechanical engineering apprenticeship course with the London Machine Tool Company, London, Ontario; was five years on development work for the Canister Machine Company and the Canada Can Company; since 1898 in the engineering department of the Electric Company.

*CHARLES FORTESCUE, transformer division, engineering department, Electric Company.

E. E. GARLITS (Casino Technical Night School, '11) entered the apprenticeship course of the Electric Company in 1907, and on completion was transferred to the detail and supply sales department, repair division, remaining until 1912, when he went to the Philadelphia repair shop of the Electric Company; at present in the detail and supply sales department specializing on fan motors and ozonizers.

JOHN GELZER, JR. (Clemson, '01) joined the Electric Company at East Pittsburgh in 1905 on testing work; later as student engineer, then in the industrial and power sales department; in 1907 entered the Atlanta district office as sales engineer, and supervised work of Birmingham sub-office for four and a half years; now assistant to district manager, Atlanta office.

JOHN J. GIBSON (Lehigh Univ., '95), machinist's apprentice, 1890-91, Pennsylvania Agricultural Works, York, Pa.; first entered employ of Electric Company summer of 1894, leaving to complete course at Lehigh Univ., re-entering the works 1895; 1896 entered the employ of American Tel. & Tel. Company as inspector in New York City; 1897 manager seventh district American Tel. & Tel. Company, Norfolk, Va.; 1898 manager Southern Bell Tel. & Tel. Company, Richmond, Va.; 1900 re-entered employ of Electric Company in Chicago sales office as chief correspondent; became salesman in Chicago office, handling large industrial customers, 1902; transferred to Philadelphia office 1905; appointed manager Philadelphia office Electric Company, 1906.

R. E. GILMAN (Leland Stanford Univ., '99), student course of the Electric Company for a year and a half; then entered engineering department on the design of alternating-current apparatus; left to take charge of induction motor design with the British Westinghouse Company in 1904, subsequently taking over all direct-current design, including railway apparatus; returned to the Electric Company at E. Pittsburgh in 1908 to design large direct-current units; from 1913 to the present time has been section engineer in charge of turbo-generator design, both direct and alternating current.

*G. BREWER GRIFFIN, manager, detail and supply sales department, Electric Company.

F. D. HALLOCK (Lehigh Univ., '94), assistant engineer and inspector sewage system layout and construction, Springfield, N. J., '94-95; in charge of White Plains Electric Street Railway, White Plains, N. J., representing L. W. Sewell, of New York, '95-96; with Crocker-Wheeler Company, Ampere, N. J., on designing and estimating, '96-98; with Electric Vehicle Company, designing original line of hansoms and broughams, electric pleasure carriages and trucks; becoming inspector of carriage body construction under contracts and later taking up costs and estimating in the same work, '98-01; came to the Electric Company in '01 in the vehicle motor and control departments on designing, testing and commercial work, followed in succession by positions in the detail engineering department on drum control and resistance for industrial service, in the industrial engineering department in the design of general industrial control, in the detail and supply engineering department in charge of the rheostat section covering rheostats and resistance for the hand control of motors and generators, in the general engineering department on control applications, and for the last two years section engineer in charge of the control section of the industrial engineering department.

E. A. HANFF (Worcester Polytechnic Inst., '10), for two years graduate student Electric Company, then entered the control section of the engineering department on the design and application of electric brakes and hand-operated machine tool controllers; is now handling in addition direct-current automatic control apparatus.

K. L. HANSEN (Univ. of Illinois) came to the United States in 1901 to enter the employ of the Western Electric Company, remaining one and one-half years, then entered the University of Illinois, remaining until 1905; entered the employ of the Rock Island Railroad; then with the Chicago Edison Company in the underground department; later a sub-station operator until 1906, when he came to the Electric Company in the wiring department, shortly entering the draughting department and subsequently the testing department and curve office; in 1909 was placed in charge of the curve office and in 1911 in charge of the curve section of the industrial engineering department; in 1912 entered upon the design of direct-current motors, remaining to date.

C. M. HARDIN (Univ. of Nebraska, '09, '10) took the apprenticeship course of The Westinghouse Machine Company, starting in 1910; after one and one-half years in the department of pricing and estimating on shop machine operations; in 1912 entered the publicity department, remaining to date.

*P. N. HARRISON, San Francisco district office, Electric Company.

J. L. HARVEY (Worcester Polytechnic Inst., '10), after apprenticeship course with Electric Company, entered the switchboard drafting department; since 1913, assistant to the system operator of the Duquesne Light Company, Pittsburgh, Pa.

G. C. HECKER (Carnegie Inst. of Tech.) entered employ of Pittsburgh Railways Company December, 1910; load dispatcher of this company, 1911-12; chief electrician since 1912.

*R. E. HELLMUND, railway engineering department, Electric Company.

JOHN S. HENDERSON (Univ. of N. Carolina, '02), with Electric Company as graduate student two years, then entered construction department, which included experience in turbine testing; in 1907 became electrical engineer Baltimore County Water & Electric Co., followed by a position as general manager of the Roanoke Virginia Water Power Co.; later consulting engineering work of a general nature in the state of North Carolina; leaving this to take a position with the Electric Company at East Pittsburgh for two years; the following two years were spent on textile work in the Boston office of the company, from which he recently returned to East Pittsburgh for similar work in the industrial and power sales department.

S. L. HENDERSON (Mass. Inst., of Tech., '10), employed in the testing department of the Electric Company for three years, then transferred to the power division of the engineering department on the design of turbo-generators, remaining to date.

*J. M. HIPPLE, engineer in charge, industrial division, engineering department, Electric Company.

W. M. HOEN (Purdue Univ., '03), graduate student with the Electric Company, followed by experience for a short time in the railway engineering department; then went to Mexico on construction and operating work for the El Oro Mining & Railway Company and the Cia Minera las Dos Estrellas, remaining for approximately five years, in the meantime doing considerable consulting engineering work; then to the Pacific coast for two years on railway and high tension transmission work, returning to the Electric Company as general engineer on mining, dredging and similar applications.

*G. H. F. HOLY, railway division, engineering department, Electric Company.

*F. L. HUTCHINSON, secretary, American Institute of Eectrical Engineers.

L. E. IMLAY, superintendent, The Niagara Falls Power Company, Niagara Falls, N. Y.

*R. P. JACKSON, research division, engineering department, Electric Company.

*H. D. JAMES, assistant to manager of engineering, Electric Company.

*J. S. JENKS, assistant general manager, West Penn Traction & Water Power Company, Pittsburgh, Pa.

F. B. JEWETT (Univ. of Chicago, '02), for two years research assistant and for two years instructor in physics and electrical engineering at Massachusetts Inst. of Tech.; entered engineering department of the American Tel. & Tel. Company in 1904; transmission and protection engineer of that company, 1907-1912; assistant chief engineer of the Western Electric Company, 1912 to date.

J. A. JOHNSON (Worcester Polytech-

nic Inst., '05), entered the engineering department of the Ontario Power Company of Niagara Falls in 1905; in charge of electrical engineering department of this company since 1911; appointed electrical engineer in 1912.

C. N. Johnson (Univ. of Wis., '09), graduate student Electric Company one and one-half years, followed by experience in testing department for a similar period, then entered the industrial and power sales department, remaining to date as a commercial engineer.

T. J. Johnston (Ag. & Mech. College of Texas, '11) came to the Electric Company as a graduate student, spending two years, after which he was transferred to the manager of works department in the department of standards, processes and materials.

W. R. Johnston (Univ. of Mich., '09), graduate student course the Electric Company, including training in the manufacture and testing of meters; then entered the industrial and power sales department in 1911, specializing on motors and control apparatus for the oil well and metal mining industries.

T. I. Jones (Mass. Inst. of Tech., '96), with the inspection and executive departments of the American Tel. & Tel. Company, 1896; illuminating engineer with the North Lamp Company in New York, 1907; organized the sales department and became sales manager of the United Electric Light & Power Company of New York; since 1909, general sales agent of the Brooklyn Edison Company.

R. L. Kimber (Syracuse Univ., '09), graduate student course the Electric Company, later accepted a position in the industrial and power sales department; specialized to date on the refrigerating and air compressing industries and has been associated with the manufacture and development of synchronous motors and their control apparatus as applied to these industries.

*G. B. Kirker, railway and lighting sales department, Los Angeles district office, Electric Company.

*H. L. Kirker, service department, Electric Company.

L. M. Klauber (Stanford Univ., '08), engineering apprentice, Electric Company to '10. With the San Diego Consolidated Gas and Electric Company, from Feb., '11, to date, serving as lighting solicitor to Dec., '12; engineer of records to July, '14, and superintendent of electric department.

W. A. LaDue became associated with the Watertown Electric Lighting Co., Ltd., in 1886; with the United States Illuminating Company, 1888; with the Jersey City Electric Company (1889) and its successors to date.

*M. B. Lambert, assistant to manager, railway and lighting sales department, Electric Company.

*B. G. Lamme, chief engineer, Electric Company; chairman, publication committee, The Electric Journal.

C. D. LaMoree, detail and supply department, Los Angeles district office, Electric Company.

J. T. Lawson, assistant superintendent, United Electric Company, Hoboken, N. J., 1897-'06; chief electrician, Marion power station, Public Service Electric Company, Jersey City, N. J., 1906-'12; chief operator, Public Service Electric Co., Newark, N. J., to date.

*Bernard Lester, commercial engineer in charge of small motor applications, industrial and power sales department, Electric Company.

C. G. Lewis (Sheffield Scientific School, '10), graduate student course Electric Company for one and one-half years, followed by a position in the industrial engineering department on the design of direct-current motors.

W. P. L'Hommedieu (Pratt Inst., '06), engineering apprenticeship course Electric Company, 1906; with the transformer engineering department, 1907-1909; with the railway and lighting sales department, 1910; railway department, San Francisco district office since 1910; at present manager railway and lighting division of this office.

*P. M. Lincoln, general division, engineering department, Electric Company; publication committee, The Electric Journal; president, American Institute of Electrical Engineers.

E. W. Lloyd, general contract agent, Commonwealth Edison Company, Chicago, Ill.

W. O. Lum, with the Magneto Electrical Company of Amsterdam, N. J., as stock and tool room keeper on industrial motor and controlling devices; then associated with Mr. C. E. Story of the Globe Electric Controller Company of Amsterdam, N. J., in general manufacturing and testing work; entered the employ of the General Electric Company in 1905, as development engineer in charge of control apparatus, remaining until 1911; came to the Electric Company in 1911 in the general engineering department, followed by a position in the control division of the engineering department in charge of development work.

*Paul MacGahan, detail and supply division, engineering department, Electric Company.

J. B. McCall, president National Electric Light Association; president, The Philadelphia Electric Company.

*W. M. McConahey, engineer in charge, transformer division, engineering department, Electric Company.

*Harold McCready, electrical department, Union Switch & Signal Company.

T. A. McDowell, head of watt-hour meter division and switchboard instrument and protective division of the detail and supply sales department, Electric Company.

Alex. McIver, railway and lighting sales department, New York district office, Electric Company.

Merritt C. McNeil (Univ. of Mich., '02) became a draughtsman with the F. F. Van Tuyl Company; 1902-03 erection engineer with Wabash Portland Cement Company; 1903-04, chief draughtsman Olds Motor Works, later becoming assistant mechanical engineer; 1904 salesman with R. D. Wood & Company; 1904-09 salesman with The Westinghouse Machine Company; 1909 to date, commercial engineer, The Westinghouse Machine Company.

*J. N. Mahoney, switchboard division, engineering department, Electric Company.

E. C. Morse (Worcester Polytechnic Inst., '06), sales engineer the Electric Company, 1906; Boston office, Electric Company, to date.

Arthur J. Motyer (Mount Allison Univ., Sackville, N. B.; obtained Rhodes' Scholarship and spent three years at Oxford Univ.; McGill Univ., '11) entered engineering apprenticeship course of the Canadian Westinghouse Company; after graduation, was transferred to engineering department after one year. At present is serving in the overseas contingent of Canadian Field Artillery.

H. C. Nagel (Cornell Univ., '04), graduate student, Electric Company, then entered the detail and supply engineering department on rheostat design, taking charge of this section in 1911.

*F. D. Newbury, engineer in charge, power division, engineering department, Electric Company; associate editor, The Electric Journal.

*S. L. Nicholson, sales manager, Electric Company.

W. B. Nicklas (Casino Technical Night School, '11) entered the employ of the Electric Company in 1902 as a tester of electrical apparatus, remaining on this work until 1906, when he was made an instructor in the industrial motor winding department; foreman of induction motor winding, 1907-11; followed by a year as foreman of graduate students; entered the industrial and power sales department in 1912, handling motors and control apparatus, wood working machinery, motor-generator sets, machine tools and metal working plants.

O. W. A. Oetting (Carnegie Inst. of Tech., '10) had one year's experience in the testing department of the Electric Company, then entered the research engineering department in electrical and magnetic investigations.

*W. H. Patterson, in charge of resale division, industrial and power sales department, Electric Company.

*W. O. Peale, in charge of heating division, detail and supply sales department, Electric Company.

*J. S. Peck, consulting engineer, British Westinghouse Electric & Mfg. Company; associate editor, The Electric Journal.

*T. S. Perkins, engineer in charge, detail and supply division, engineering department, Electric Company.

*Luther P. Perry, power engineer, The Narragansett Electric Lighting Company, Providence, R. I.

*J. F. Peters, transformer division, engineering department, Electric Company.

*G. Pontecorvo, industrial division, engineering department, Electric Company.

L. Pontecorvo (Univ. of Turin, '94), assistant to Professor Galileo Ferraris for one year; went to Ganz & Company, Budapest, and with Mr. K. de Kando started the first experiments for the three-phase electrification of the experimental line built by Ganz & Company in Budapest; in Italy on the electrification of the Valtellina line in 1902; shortly after left the employ of Ganz & Company, and with Mr. de Kando joined the Westinghouse interests in Europe and, under Mr. Westinghouse, co-operated in the founding of the Societa Italiana Westinghouse, with which company he has been associated to date; at present one of the managers of this company and a member of the board of directors.

*A. G. Popcke, for the past two years associated in the industrial and power sales department with the development of new electrical apparatus for industrial applications particularly motors and their control.

R. R. Potter, superintendent of equipment, New York, Westchester & Boston Railway. Previously connected with Interborough Rapid Transit Company, Long Island Railroad Company, Hudson & Manhattan Railroad Company, and the engineering firm of L. B. Stillwell.

W. A. Rankin entered the testing department of the Electric Company in 1889; was with the Phoenix Iron Works

Company of Meadville, Pa., as erector of steam plants during 1890-93; again with the Electric Company as erector from 1894-96; with the Anaconda Copper Mining Company from 1896-02, in their street railroad department, electrolytic refinery department, and as foreman of electrical construction on their new smelting works; with the Michigan Smelting Company, Houston, Mich., as superintendent of all construction, 1903-05; and with the Copper Range Consolidated Company as electrical engineer from 1906 to date.

*H. A. Rapelye, Pittsburgh office, The Westinghouse Machine Company.

*E. G. Reed, transformer division, engineering department, Electric Company.

*A. E. Rickards, general manager, Industrial Engineering Company, Pittsburgh, Pa.

F. E. Ricketts, superintendent of electric stations, Consolidated Gas, Electric Light & Power Company, Baltimore, Md.

*Chas. R. Riker, technical editor, The Electric Journal.

W. M. Robbins (Cornell Univ., '09), one year graduate student course the Electric Company; followed by a study of the use of electricity in the coal fields of West Virginia for a year; in the industrial and power sales department on mining and other industrial locomotive work.

W. H. Rolinson, commercial engineer, Westinghouse Lamp Company; previously connected with the Electrical Testing Laboratories.

*G. W. Roosa, detail and supply sales department, Electric Company.

*G. B. Rosenblatt, commercial engineer, Electric Company, specializing on mining work in the western district of the United States.

*Chas. F. Scott, professor of electrical engineering, Sheffield Scientific School, Yale Univ.; associate editor, The Electric Journal.

Thomas Shaw (Mass. Inst. of Tech., '05), since graduation, employed in the transmission and protection division, engineering department, American Tel. & Tel. Company, being principally engaged in the design and development of coils for use in telephone and telegraph circuits.

T. E. Simpers (Univ. of Penn., '07), graduate student course the Electric Company; then in the industrial and power sales department in connection with the sale of motors and their control apparatus for the rubber, paper, cement, brick, quarry, grain elevator, flour mill and glass industries.

*C. E. Skinner, engineer in charge, research division, engineering department, Electric Company; associate editor, The Electric Journal.

*B. H. Smith, detail and supply division, engineering department, Electric Company.

H. M. Southgate (Worcester Polytechnic Inst., '92, post-graduate, '93), with the Electric Company at East Pittsburgh until 1895, afterwards being connected with the Boston sales office until 1899; held positions as district office manager, manager of the plant department, deputy sales manager with the British Westinghouse Company in London and Manchester, England, until 1910; since which date has been manager of the Washington, D. C., office of the Electric Company.

F. C. Stanford, after leaving school, became interested in various small public utilities in Illinois as manager and part owner; with the Rocky Mountain Bell Telephone Company in Idaho and Utah for five years as district manager and division superintendent; became general superintendent of American Falls Power Company and Idaho Consolidated Power Company; later with Peoria Gas & Electric Company and United States Gas & Electric Company; with the Cleveland Cliffs Iron Company as chief electrician since 1910.

*C. W. Starker, industrial division, engineering department, Electric Company.

B. W. Stemmerich took charge of shop production and records with the Electric Company in 1892; 1895-1900 was in charge of all general order and stock order production; 1900-1904 in charge of sales correspondence on direct-current locomotives and motors; 1904 to date, equipment division, railway and lighting sales department.

W. W. Stevenson (Kentucky State Univ., '11), with the Babcock & Wilcox Boiler Company, Barberton, Ohio, for a short time, leaving this company to take a position as assistant to the works steam engineer, Electric Company.

G. E. Stoltz (Ohio State Univ., '09), graduate student course Electric Company, remaining for two years; at present general engineering department on the application of motors and their control to steel mills.

*E. C. Stone, system operator, Duquesne Light Company, Pittsburgh.

*N. W. Storer, general railway engineer, engineering department, Electric Company; associate editor The Electric Journal.

*A. F. Strouse, Industrial Engineering Company, Pittsburgh, Pa.

Wilfred Sykes (Melbourne Univ., Australia, 1900) entered the employ of the Allgemeine Elektricitäts Gesellshaft as general engineer and manager, followed by two years with the same company in Berlin as engineer on large industrial applications; then came to the Electric Company, remaining to date as general engineer in charge of the industrial section.

R. H. Taber (Worcester Polytechnic Inst., '09-11), after graduation remained two years as instructor in electrical engineering design; since then with the Electric Company on the design of direct-current motors and generators.

A. Merritt Taylor, four years' apprenticeship course in the machine tool works of William Sellers & Company; president, Philadelphia & West Chester Traction Company since January, 1899; president, New Jersey & Hudson River Railway and Ferry Company from 1902 to 1910; transit commissioner, City of Philadelphia from May, 1912, to July, 1913; director, department of City Transit, Philadelphia, since July, 1913.

*H. B. Taylor, detail and supply division, engineering department, Electric Company.

*W. E. Thau, Electric Company, general engineering department on the application of motors and their control apparatus to steel mills.

Phillips Thomas (Ohio State Univ., '04, Princeton, '12) entered the employ of the Western Electric Company as tester and engineering draughtsman; then instructor in electrical engineering, Princeton University, remaining until 1911; since 1911 with the Electric Company in research division, engineering department on condensers and insulation characteristics.

*W. A. Thomas, consulting engineer, Pittsburgh, Pa.

*Calvert Townley, assistant to president, Electric Company, New York City.

Guy E. Tripp entered the employ of the Eastern Railroad before its consolidation with the Boston & Maine, and later was employed by the Thompson-Houston Electric Company in the work of electrifying the West End Street Railway of Boston; upon the completion of that work, and at the time of the consolidation of the Thompson-Houston Electric Company, with the Edison Company into the General Electric Company, he became traveling auditor for the latter. He then joined the Industrial Improvement Company, which was controlled by the General Electric Company, where he had charge of the accounting and financial departments of the interests owned by it. In 1897 he became connected with Messrs. Stone & Webster, for whom he managed the Western investments, which lay principally in Texas and on the Pacific coast; has advised and directed the financing, organization and reorganization of some of the largest public utility corporations in the country. For some time Mr. Tripp was prominently identified with the reorganization of the Metropolitan Street Railway, New York City, representing Stone & Webster, who were retained by the bondholders' committee. He was made chairman of the joint committee on reorganization, and the plan under which the reorganization of the Metropolitan Street Railway has been effected was drawn under his supervision. He was vice president of the Stone & Webster Management Association and of the Stone & Webster Engineering Corporation, from both of which he resigned to devote all of his time to the Westinghouse Company. At the time of his election as the chairman of the board of directors of the Westinghouse Electric & Mfg. Company, Mr. Tripp was president of a large number of public service companies allied with the Stone & Webster interests. He has recently been elected president of the West Penn Traction & Water Power Company.

G. T. Twyford (W. Va. Univ., '11), with the Electric Company at East Pittsburgh in testing department and railway engineering department, 1911-1913; since 1913 master mechanic, the Pittsburgh, Harmony, Butler & New Castle Railway Company.

B. H. Ulrich (Carnegie Inst. of Tech., '08), engineering apprentice with the Electric Company, 1909-11; with Pennsylvania Railroad as inspector of electric locomotives at New York City; with the Electric Company on motor applications to machine tools, 1911-12; with Industrial Engineering Company of Pittsburgh, 1912-14; general engineering department, Electric Company on electric vehicle motor applications to date.

Gordon Weaver (Penn. State, '05, '09) entered the student course of the Electric Company after graduation; in 1905 in inspection department of the Union Switch & Signal Company at Swissvale, and was later transferred to the engineering department of the latter company; in December, 1906, went with he Animas Power & Water Company, of Silverton, Colorado, as draftsman and assistant superintendent; when the Animas Power & Water Company was reorganized in 1909, was made assistant general manager of new company (San

Juan Water & Power Company); went with the Union Electric Light & Power Company of St. Louis in 1910 as power engineer; in 1911 accepted position with Kansas City Electric Light Company as industrial engineer, and was made power sales manager in 1913.

C. A. M. WEBER (Alabama Polytechnic Inst., '06, '07, and '14) remained one year as instructor of physics, then to the Electric Company as a graduate student; then entered the small motor division of the engineering department on the design and application of small motors.

*J. W. WELSH, electrical engineer and traffic manager, Pittsburgh Railways Company.

H. M. WIBLE, three years at the Western Pennsylvania Institute, and came to the Electric Company in 1902, spending several years in the shop and testing department; in 1909 entered the detail and supply sales department, remaining to date.

H. M. WICKER commenced electrical work for the Spragues Electrical Co., 1901; this was followed by construction, inspection and test work in New York for the Brooklyn Rapid Transit Co., the Interboro Rapid Transit Co., and the Electric Mfg. Company, including changes and test work on the high-tension trolley system at Sea Cliff, L. I., and the N. Y., N. H. & H. R. R. at Stamford, Conn.; foreman of the assembling department of the Gold Car Heating Co., in New York, 1905; did further experimental work in electric heating in 1907, developing a car heater and a linotype pot heater, applying the parallel series system to the control of heating; in 1912 joined the Electric Company in the electric heating division; at present with the New York district office.

*BRENT WILEY, commercial engineer in charge of the application of motors and their control apparatus to steel mill service, industrial and power sales department, Electric Company.

L. C. WINSHIP (Mass. Inst. of Tech., '05), engineering apprentice with the Electric Company, 1905-06; entered the railway engineering division in fall of 1906; engaged in electric locomotive testing on Pennsylvania Railroad and in the installation of the electric operation of the N. Y., N. H. & H. R. R. for the Electric Company, 1907-08; with the N. Y., N. H. & H. R. R. in connection with the operation of the electric zone, 1909-10; with the Boston & Maine Railroad in 1911, as electrical superintendent in charge of electrical operation of the Hoosac Tunnel; supervisor of power plants for the same company, 1914.

J. M. WOLTZ (Univ. of Cincinnati, Medical Dept., 1900), safety director, Youngstown Sheet & Tube Company, in charge of safety, sanitation and welfare work since July, 1913.

*F. E. WYNNE, general division, engineering department, Electric Company.

*J. L. McK. YARDLEY, power division, engineering department, Electric Company.

E. S. ZUCK (Ohio State Univ., '07), one and one-half years on graduate student course, Electric Company; followed by one and one-half years in the industrial and power sales department; Cleveland office as commercial engineer on control apparatus; transferred to the Pittsburgh office for a year and then to the general engineering department as engineer on motor applications, specializing in arc welding outfits.

Contributors to the Journal Question Box---1914

The following list of contributors who have furnished answers to inquiries published in THE JOURNAL QUESTION BOX *during the present year indicates in a general way the sources from which this information is obtained, but does not take into account the many questions answered by direct correspondence. This department of the* JOURNAL *is at the disposal of subscribers as a means of obtaining advice on electrical and mechanical topics. Except where otherwise stated, the contributors are associated with the Electric Company:*

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OF

THE ELECTRIC JOURNAL

WITH

INDEX TO AUTHORS

FOR

VOL. XI - - 1914

PUBLISHED BY
THE ELECTRIC JOURNAL
PITTSBURGH, PA.

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VOLUME XI

THIS Index, as well as the Ten Year Topical Index, issued as a supplement to the Journal for Jan. 1914, is arranged according to the topical classification of subjects. The original scheme for this method of indexing was published in the Journal for February, 1906. All articles which have appeared in the Journal since its initial issue can be located quickly by the use of the Ten Year Topical Index and the present Index, which covers the first year of the second decade

Abbreviations: *T*-Number of Tables; *C*-Number of Curves; *D*-Number of Diagrams; *I*-Number of Illustrations; *W*-Number of words; *Q.B.*-Question Box. The main headings and sub-division are as follows:

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